



# ARIZONA GAME AND FISH DEPARTMENT

RESEARCH BRANCH  
TECHNICAL REPORT #22

## FACTORS AFFECTING THE RAINBOW TROUT FISHERY IN THE HOOVER DAM TAILWATER, COLORADO RIVER

*A Final Report*

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June 1996

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FISH RESTORATION PROJECT

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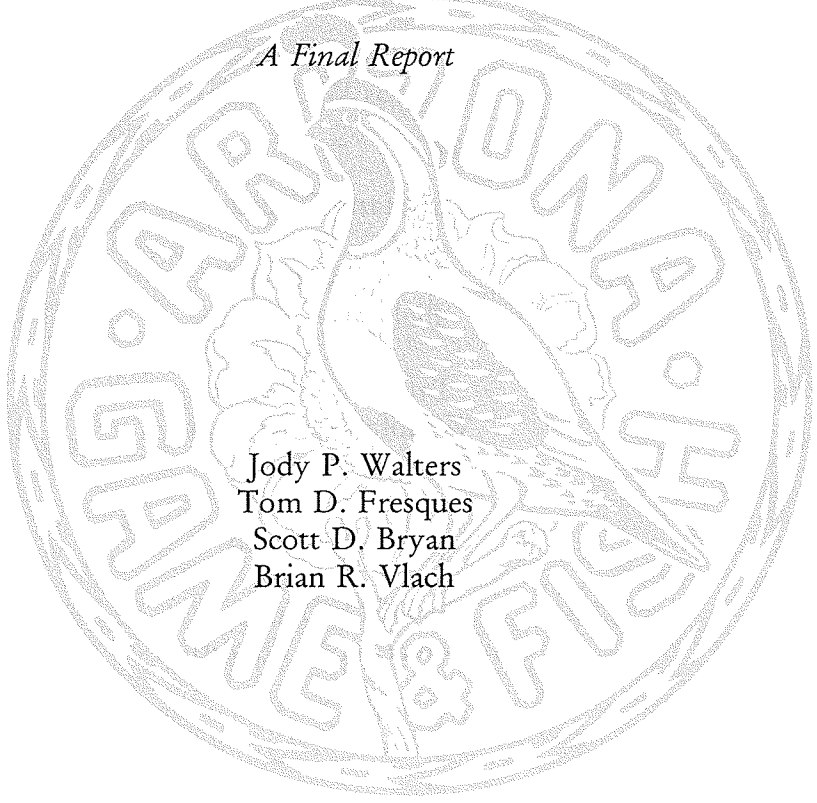
*To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.*

Arizona Game and Fish Department  
Research Branch

Technical Report Number 22

**Factors Affecting the Rainbow Trout Fishery in the  
Hoover Dam Tailwater, Colorado River**

*A Final Report*

The seal of the Arizona Game and Fish Department is a circular emblem. It features a central illustration of a desert landscape with a saguaro cactus, a mountain range, and a river. The words "ARIZONA" and "GAME & FISH" are inscribed around the perimeter of the seal, separated by small decorative elements.

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June 1996

Federal Aid in Sport Fish Restoration

Project F-14-R

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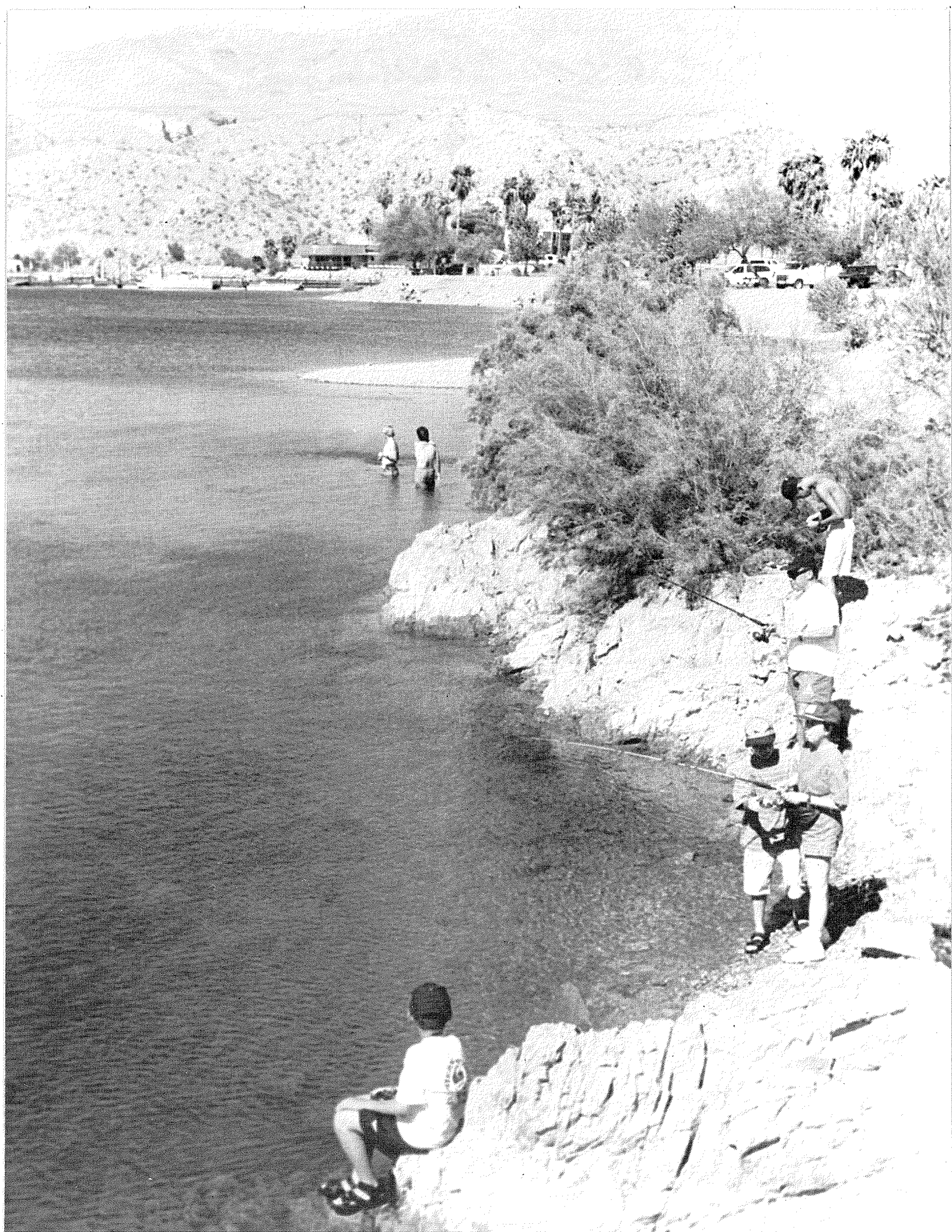
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# FACTORS AFFECTING THE RAINBOW TROUT FISHERY IN THE HOOVER DAM TAILWATER, COLORADO RIVER

Jody P. Walters, Tom D. Fresques,  
Scott D. Bryan, and Brian R. Vlach

**Abstract:** We conducted this study from 1993-1995 to determine what caused a decline in numbers of trophy ( $\geq 508$  mm total length) rainbow trout (*Oncorhynchus mykiss*) harvested from the Hoover Dam tailwater, and to learn what factors currently limit the fishery. The Hoover Dam tailwater supported a trophy rainbow trout fishery in the 1960s and early 1970s. By the late 1970s, the percentage of trophy fish harvested decreased, as did angling effort. Currently, a put-and-take rainbow trout fishery exists, along with a striped bass (*Morone saxatilis*) fishery. We investigated stocking practices, and determined diet and sources of mortality of stocked rainbow trout. We also surveyed indicators of biological production in the tailwater. Angling exploitation of stocked fish was 2.6%, but annual survival was near 0. Rainbow trout comprised 98% of food item volume in large ( $\geq 400$  mm) striped bass stomachs. Occurrence of rainbow trout in large striped bass stomachs decreased, while occurrence of cladocerans and chironomid pupae increased,  $>2$  weeks after rainbow trout were stocked. This change in diet suggests that stocked fish were quickly depleted by predation, forcing large striped bass to switch to other food items. Chironomid pupae, aquatic macrophytes, and algae made up 18.8, 11.6, and 10.0% of the rainbow trout diet, respectively. Chlorophyll-*a* and nutrient concentrations were lower than those measured in the Hoover Dam tailwater in the mid 1970s. Willow Beach National Fish Hatchery typically stocked catchable ( $\bar{x} = 203$  mm) fish from 1963-1973. However, mainly subcatchable fish were stocked from 1974-1978, which may have led to decreased survival and growth of these fish. In addition, rainbow trout growth may have decreased due to a declining threadfin shad (*Dorosoma petenense*) forage base. Striped bass predation currently limits the rainbow trout fishery. Rainbow trout returns may be improved by stocking fish every 2 weeks, stocking larger fish, and concentrating stocking near Willow Beach Marina.

**Key words:** angling exploitation, Colorado River, *Morone saxatilis*, nutrients, *Oncorhynchus mykiss*, rainbow trout, striped bass, tailwater.

## INTRODUCTION

The Hoover Dam tailwater (Willow Beach) once supported a trophy rainbow trout fishery, popular throughout the southwestern United States. The tailwater has been stocked with rainbow trout since 1935, when Hoover Dam began releasing cold water from the hypolimnion of Lake Mead. Jonez and Sumner (1954) stated that rainbow trout fishing was "excellent" in the tailwater prior to Lake Mohave filling in 1951, and reported that at least 2-8.17 kg rainbow trout and 1-8.02 kg fish were caught between 1950 and 1954.

In 1962, Willow Beach National Fish Hatchery (WBNFH) began operation approximately 18 km downstream from Hoover Dam. Willow Beach National Fish Hatchery stocked 202,000-673,000 catchable ( $\bar{x}=203$  mm total length) rainbow trout into Lake Mohave and the Hoover Dam tailwater annually from 1963-1974. The Nevada Division of Wildlife also stocked 28,000-118,000 catchable rainbow trout annually during this period. These stockings supported a put-grow-and-take tailwater fishery.

Although the tailwater did not meet the criteria of a "Blue Ribbon" fishery (Arizona Game and Fish Department 1984), catches of trophy ( $\geq 508$  mm) rainbow trout were common in the 1960s and early 1970s. The Arizona state record rainbow trout (9.2 kg) was caught from the tailwater in 1966.

By the late 1970s, the percentage of trophy rainbow trout harvested began to decline (Nev. Div. of Wildl., unpubl. data; Fig. 1). Further evidence of this declining fishery was a decreasing trend in angling effort after 1979 (Nev. Div. of Wildl., unpubl. data; Fig. 2). As of 1993, mainly a put-and-take fishery remained, with  $<0.5\%$  of the yearly harvest being trophy rainbow trout (T. Liles, Ariz. Game and Fish Dep., pers. commun.).

We initiated this study to learn what factors caused the decline in this fishery. We hypothesized that low survival or growth rates of stocked rainbow trout led to this decline. In addition, we investigated which factors currently limit the rainbow trout fishery, as the dynamics of the fishery may have changed since the 1970s.

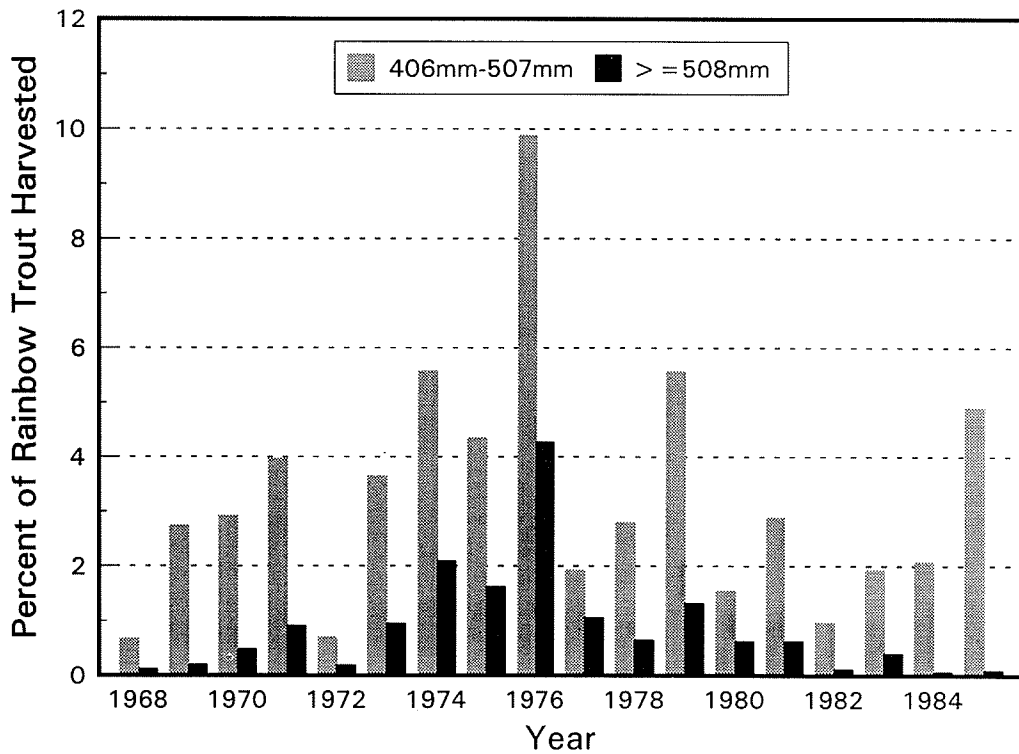


Figure 1. Percent of rainbow trout harvested from the Hoover Dam tailwater which were 406-507 mm, and  $\geq 508$  mm, 1968-1985 (Nev. Div. of Wildl., unpubl. data).

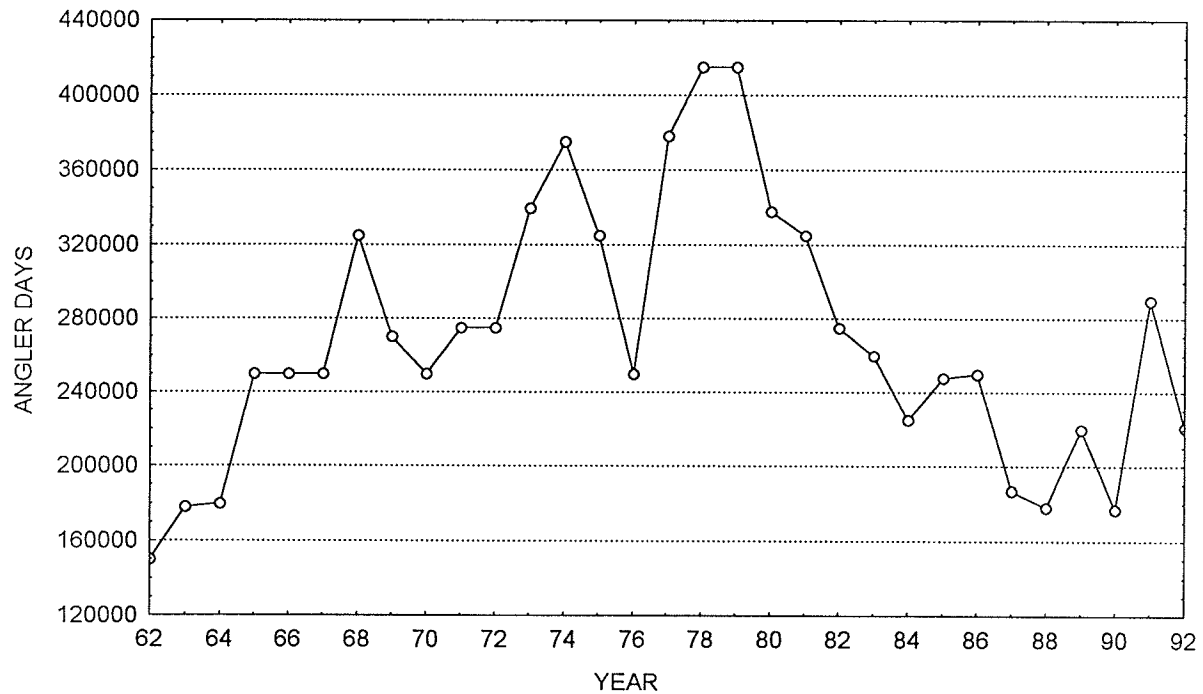


Figure 2. Total number of angler days on Lake Mohave, including the Hoover Dam tailwater (Nev. Div. of Wildl., unpubl. data).

Overharvest by anglers can have detrimental impacts on sport fisheries (Hickman and Congdon 1974, Redmond 1974). The popularity of the Hoover Dam tailwater rainbow trout fishery in the 1960s and 1970s, may have led to overharvest of stocked fish. Overharvest may have lowered survival, preventing rainbow trout from attaining trophy size. Current exploitation rates (number of stocked rainbow trout returned to the creel) are unknown.

Striped bass predation may also limit rainbow trout survival (Edwards 1974, Deppert and Mense 1979, Eichner and Ellison 1983). Striped bass were not intentionally introduced into the Hoover Dam tailwater or downstream in Lake Mohave, but may have entered as eggs or fry through Hoover Dam from Lake Mead (Liles 1988). They were first documented in Lake Mohave in 1981 when 11 fish ( $\bar{x}$  = 400 mm) were collected during routine sampling by Arizona Game and Fish Department. Three striped bass were also caught by anglers in 1981, the largest weighing 10.5 kg (T. Liles, Ariz. Game and Fish Dep., pers. commun.). Age 0 striped bass were first collected in July 1987 (Liles 1988). Before 1989, striped bass comprised <1% of the creel at Willow Beach, but by 1991 they constituted 52% of the harvest (Nev. Div. Of Wildl., unpubl. data).

Striped bass numbers were not high enough in the 1970s to have caused the rainbow trout fishery decline. However, the recent increase in striped bass harvest, along with observations of predation on stocked rainbow trout, suggests that predation may now limit the fishery (T. Liles, Ariz. Game and Fish Dep., pers. commun.). Biologists have not quantified the extent of this predation.

Low growth rates, due to a decreasing food base, may have been another factor affecting the rainbow trout fishery. The Colorado River inflow to Lake Mead was unregulated until 1963, when Lake Powell was formed by the closing of Glen Canyon Dam. Lake Powell became a nutrient sink, retaining nitrates, phosphorus and sediments, thus reducing their input to Lake Mead (Gloss et al. 1980, Paulson and Baker 1981, Evans and Paulson 1983). This nutrient input reduction, along with a change in the Hoover Dam flow regime (Fig. 3), may have reduced nutrient loading in the Hoover Dam tailwater. In addition, in 1981, improvements were made to the Las Vegas, Nev. waste water treatment plant, which lowered the phosphorus concentration of treated effluent to 0.1 mg/l (Paulson and Baker 1983). Because the effluent enters Lake Mead via Las Vegas Wash near Hoover Dam, this may have caused a further reduction in the phosphorus concentration of the

tailwater. Lower nutrient concentrations may have decreased productivity, resulting in less rainbow trout food resources available through bottom up controls (Menge 1992).

Certain salmonid strains show differences in growth and survival rates, and other traits (Cordone and Nicola 1970, Kincaid 1981, Brauhn and Kincaid 1982, Moring 1982). Also, stockings of subcatchable (<203 mm) rainbow trout are known to give inferior creel returns, compared with catchable size fish (Needham 1959, Cresswell 1981, Wiley et al. 1993). Thus, changes in WBNFH stocking practices may have affected the Hoover Dam tailwater fishery.

Since Jonez and Sumner's (1954) work, the ecology of the Hoover Dam tailwater and how it affects the rainbow trout fishery have received limited attention (Nev. Div. of Wildl., unpubl. data, Paulson et al. 1980 *a,b*, Liles 1988). Fisheries managers need more quantitative data to determine what caused the decline, or what currently limits the fishery. This information can be used to plan recovery of the rainbow trout fishery, or to develop other management plans suitable to the current ecological status of the tailwater.

Therefore, the objectives of this study were to:

- Measure exploitation, survival, and growth rates of stocked rainbow trout to determine if the tailwater can still produce trophy rainbow trout.
- Document differential exploitation rates of rainbow trout, based on stocking location.
- Determine the extent of striped bass predation on stocked rainbow trout.
- Identify diet overlap between rainbow trout and striped bass that may suggest competition for food, thus limiting growth rates of rainbow trout.
- Determine the source, and spatial and temporal distribution of zooplankton within the tailwater, because zooplankton may be a food item for stocked rainbow trout.
- Determine the diversity, density, and distribution of benthic invertebrates that may also serve as rainbow trout food.
- Measure water nutrient and chlorophyll-*a* concentrations, and physicochemical variables.

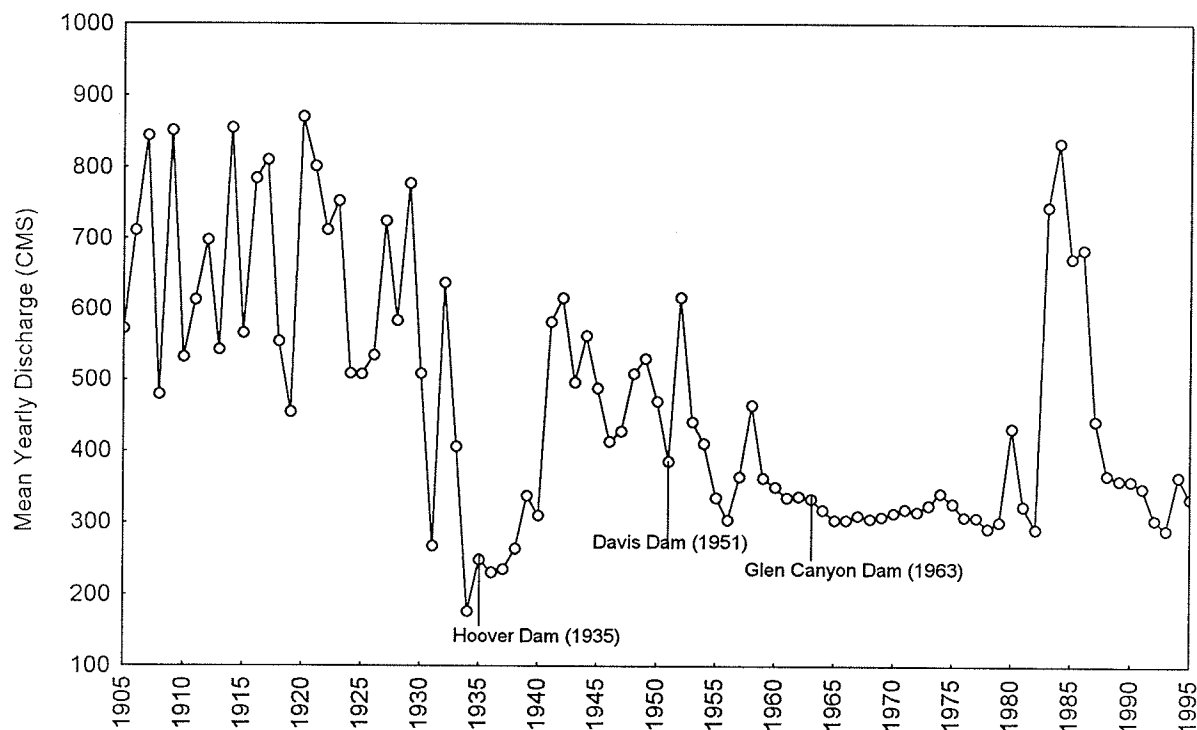


Figure 3. Mean yearly Colorado River discharge  $m^3/s$  (cms) at the U.S. Geological Survey gauging station below the site of Hoover Dam, 1905-1995.

- Determine if tailwater productivity has decreased by comparing current zooplankton and benthos densities, and water nutrient and chlorophyll-*a* concentrations with those reported in previous studies.
- Review hatchery records for information concerning changes in stocking practices or strains of rainbow trout stocked since 1963, which may have affected the fishery.
- Determine the relative abundances of fish species in the tailwater for baseline data on the fish community.
- Present management options to enhance the Hoover Dam tailwater sport fishery.

## STUDY AREA

Hoover Dam is on the Colorado River in northwest Arizona and southeast Nevada. The dam releases cold (12 to 14 C) water from the hypolimnion of Lake Mead year round. Our study reach encompassed 789 ha of tailwater, extending 42 km downstream from Hoover Dam to Eldorado Canyon (Nev. Mile Marker 39; Fig.

4), at the upstream end of Lake Mohave proper. Mean annual discharge from Hoover Dam during the study was 292  $m^3/s$  (August-December 1993), 362  $m^3/s$  (1994), and 346  $m^3/s$  (1995) (Table 1).

For stocking purposes, Lake Mohave was divided into 7 areas. The Hoover Dam tailwater includes Areas 6 and 7 (Fig. 4). Area 7 extends from Hoover Dam to Arizona Mile Marker 52 (AZ 52), which includes Willow Beach Marina. Area 6 extends from AZ 52 to Nevada Mile Marker 39 (NV 39). Willow Beach Marina is the only improved access point along the tailwater. Three other access points provide limited shoreline fishing, and receive insignificant use compared with Willow Beach Marina (M. Burrell, Nev. Div. of Wild., pers. commun.).

Rainbow trout, channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), razorback suckers (*Xyrauchen texanus*), and striped bass are the only fish that regularly inhabit the tailwater. No natural rainbow trout recruitment occurs due to a lack of appropriate spawning substrate (T. Liles, Ariz. Game and Fish Dep., pers. commun.).

For comparative purposes, we selected 4 sampling sites that were previously surveyed in the late 1970s (Paulson et al. 1980 *a,b*, Priscu et al.



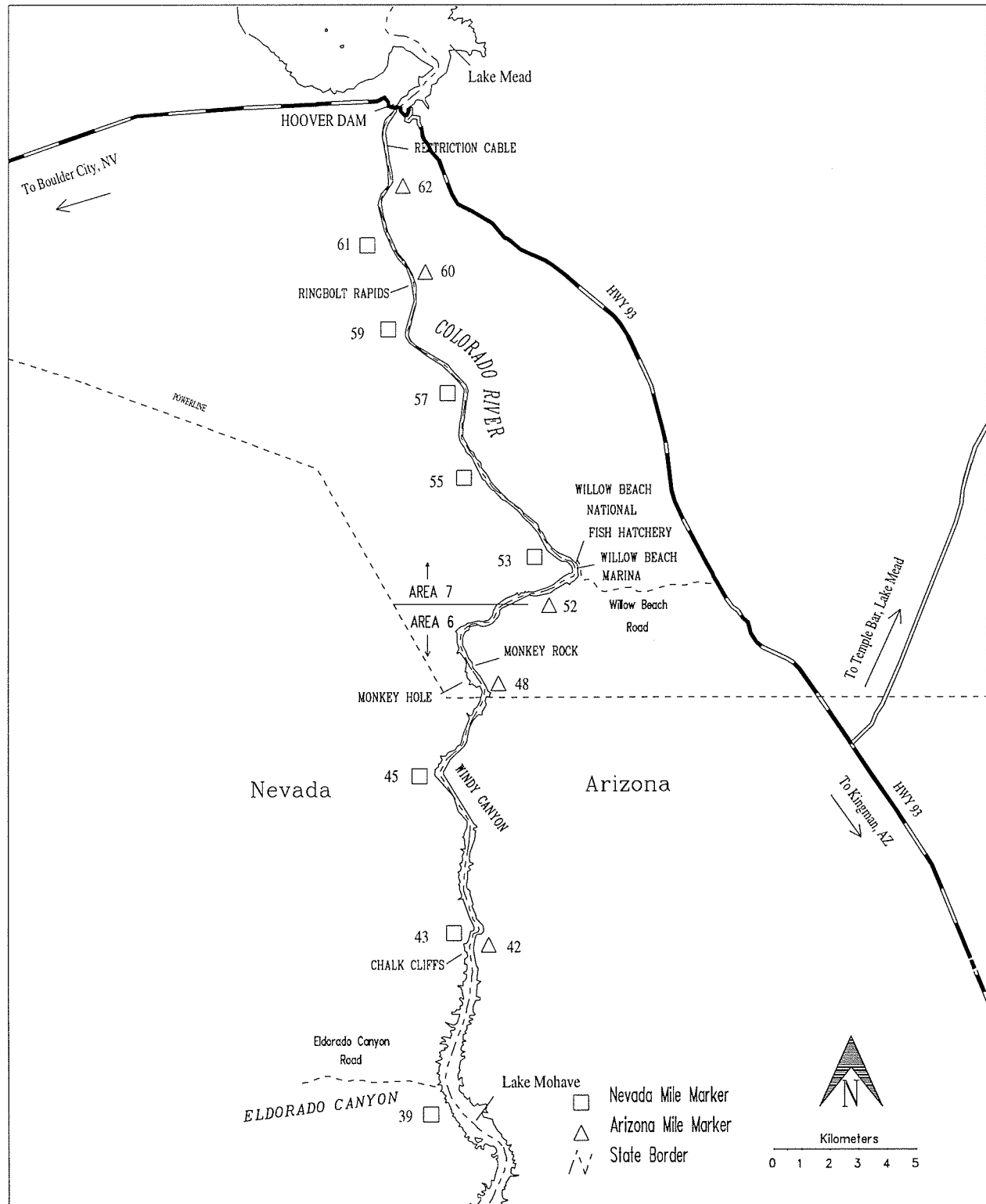


Figure 4. Hoover Dam tailwater study area.

1982). The sites included Hoover Dam (about 300 m upstream from the restriction cable), Ringbolt Rapids (AZ 60), Monkey Hole (AZ 48), and Eldorado (NV 39; Fig. 4). At the Hoover Dam and Ringbolt Rapids sites, steep canyon walls confine the tailwater to a narrow channel (126 m and 148 m at the Hoover Dam and Ringbolt Rapids sites, respectively), keeping flows swift. At

Monkey Hole, the tailwater is less confined, resulting in some shallow shoreline areas and slower flows. The Eldorado site is more lentic in nature, occurring at the upper end of Lake Mohave where the cold tailwater meets the warmer lake water. The water thermally stratifies at the Eldorado site in summer.

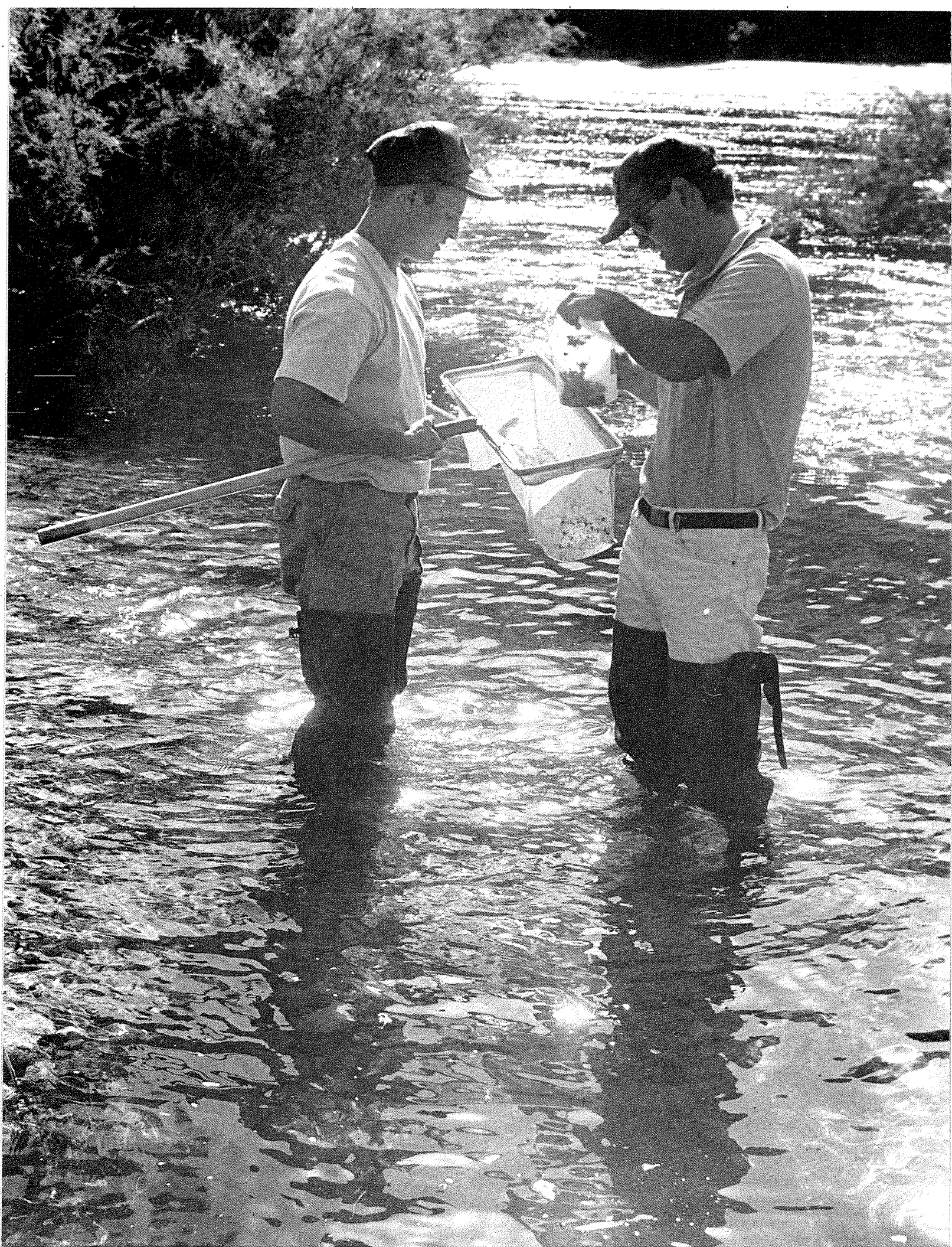
Table 1. Hoover Dam discharge ( $\text{m}^3/\text{s}$ ), August 1993-December 1995.

Date	<i>n</i>	Mean	Minimum	Maximum
1993				
Aug	31	328.0	119.8	532.4
Sep	30	245.7	94.3	396.5
Oct	31	305.5	161.7	464.5
Nov	30	254.1	137.4	405.0
Dec	31	341.1	192.6	444.6
1994				
Jan	31	282.0	132.3	439.0
Feb	28	296.7	126.9	444.6
Mar	31	462.0	250.9	691.0
Apr	30	524.4	308.7	631.5
May	31	477.3	294.5	691.0
Jun	30	396.2	223.4	574.9
Jul	31	382.8	246.1	506.9
Aug	31	413.0	212.7	577.7
Sep	30	274.3	143.9	472.9
Oct	31	257.2	122.1	351.2
Nov	30	347.5	190.3	515.4
Dec	31	272.5	170.8	393.7
1995				
Jan	31	158.5	77.0	368.2
Feb	28	232.0	141.6	322.9
Mar	31	414.3	232.5	569.2
Apr	30	473.4	245.0	671.2
May	31	402.2	181.5	594.7
Jun	30	411.1	220.1	543.7
Jul	31	371.5	208.2	512.6
Aug	31	441.1	252.6	572.1
Sep	30	322.2	184.1	501.3
Oct	31	282.0	143.9	424.2
Dec	31	333.6	162.1	449.7



A successful angler at Willow Beach.







## METHODS

### Rainbow Trout Exploitation and Survival

To monitor the proportion (by number) of stocked rainbow trout returned to the creel and their survival, we marked their snouts with binary coded wire tags (Northwest Marine Technology, Inc., Shaw Island, Wash.) before stocking. We stocked rainbow trout in the Hoover Dam tailwater from October 1992-July 1994 (Table 2). We used a different tag code to identify cohorts by stocking area and date stocked. We held fish in outside raceways for a recovery period of at least 21 days after they were tagged, but we stocked them at the same size (203-254 mm) and on the same schedule as fish normally stocked by WBNFH. The day before each stocking, we measured a subsample of 300 fish for tag retention. We used the proportion of tagged fish within this subsample to estimate the number of tagged fish stocked (Table 2). The Nevada Division of Wildlife did not stock the tailwater during our study.

We also held 52 tagged fish in a hatchery raceway for 223 days to monitor long-term tag retention. However, Blankenship (1990) reported tag retention rates of 94.7-98.9% for chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon and found no significant tag loss later than 29 days after tagging.

We did not stock fish from April-June 1994. During this period, WBNFH entered Endangered Species Act (ESA) Section 7 informal consultation with the U.S. Fish and Wildlife Service (USFWS) regarding the effect of stocking nonnative rainbow trout in the Hoover Dam tailwater and Lake Mohave. The USFWS determined that stocking rainbow trout "may affect" but would not "adversely affect" endangered razorback suckers and bonytail chubs (*Gila elegans*). Therefore, we resumed stocking rainbow trout in July 1994.

We conducted an access point creel survey at Willow Beach Marina from September 1993-October 1995 to monitor tag returns. Our creel design followed that of Hayne (1991). Five weekday and 2 weekend sample days were randomly chosen for each half month. September 1993-April 1994 creel days began about 1 hr before sunrise and ended about 1 hr after sunset. Sample days were divided into equal length work periods. May 1994-October 1995 creel days were 24 hrs long, divided into 6 equal work periods. One work period was randomly selected for each sample day. We estimated monthly angling effort (hrs) and rainbow trout harvest based on

completed trip interviews. We calculated rainbow trout catch per unit effort monthly as total projected harvest divided by total projected effort (hrs).

During our creel survey, we removed snouts from rainbow trout with tags. In the lab, we extracted the tags and read them to determine the stocking date and area for each fish. We calculated exploitation rates for rainbow trout stocked from September 1993-July 1995, and estimated survival for fish stocked from November 1992-July 1995 (Ricker 1975).

### Striped Bass and Rainbow Trout Diets

We examined stomach contents to quantify striped bass predation and diet overlap with rainbow trout. We collected striped bass and rainbow trout stomachs from angler harvested fish, and from fish captured during netting and electrofishing. We obtained stomachs from a maximum of 20 large ( $\geq 400$  mm) and 20 small ( $< 400$  mm) striped bass, and 50 rainbow trout each month. In the laboratory, we identified food items to Order or Family, counted them, and measured each taxonomic group by volumetric displacement.

### Zooplankton

We sampled zooplankton every other month (bimonthly) from February 1994-December 1995, to determine their source, and spatial and temporal distribution. We collected 3 vertical tow samples at random points along a transect running perpendicular to the flow of water at each site. We collected February-August 1994 samples with a 0.130 m diameter Wisconsin net, and October 1994-December 1995 samples with a 0.305 m diameter tow net. We assumed both nets were equally efficient at sampling zooplankton densities because net mesh and bucket mesh sizes were 80  $\mu$ m for each net. We began tows as near bottom as possible while maintaining a retrieval perpendicular to the surface, because strong winds and currents caused the boat and net to drift at different rates. We calculated total volume of water filtered as net opening area multiplied by tow length. Zooplankton were preserved in 50% isopropanol.

We concentrated each zooplankton tow sample to 50 ml before analysis. Zooplankton were then identified to Family, and enumerated from 5 subsamples. We chose 1- or 2-ml subsamples so that at least 60 organisms were counted. If  $\leq 60$  organisms were found in a

Table 2. Exploitation of tagged cohorts of rainbow trout stocked into the Hoover Dam tailwater.

Year	Month	Day	Area <sup>a</sup>	No. of tagged rainbow trout stocked	Projected no. of tagged rainbow trout harvested	Exploitation rate <sup>b</sup>
1992	10	5	6	10,008	0	0.000
	10	6	7	10,357	0	0.000
	10	25	7	10,523	0	0.000
	11	2	6 & 7	18,391	41	0.002
	12	2	6	7,524	0	0.000
1993	1	--	6 & 7	18,146	0	0.000
	5	5	--	7,559	635	0.084
	7	18	6	13,581	23	0.002
	7	19	7	14,079	32	0.002
	8	17	6	10,955	21	0.002
	8	18	7	10,439	481	0.046
	8	24	6	13,591	41	0.003
	9	14	7	16,905	1,106	0.065
	9	15	6	11,352	22	0.002
	9	27	7	14,347	1,220	0.085
	11	2	7	11,556	1,732	0.150
	11	4	6	9,859	364	0.037
	11	23	6	17,414	235	0.013
	12	28	7	16,688	0	0.000
1994	1	26	6	15,893	0	0.000
	2	16	7	16,985	60	0.004
	3	16	6 & 7	16,756	33	0.002
	7	1	6	11,623	33	0.003
	7	1	7	13,007	410	0.032
	7	6	6	10,711	21	0.002
	7	6	7	13,156	199	0.015
	7	6	6 & 7	9,832	119	0.012
	7	7	7	10,657	147	0.014
Total				361,894	6,975	0.026 <sup>c</sup>

<sup>a</sup> Area 6 = Nevada Mile Marker 39 to Arizona Mile Marker 52; Area 7 = Arizona Mile Marker 52 to Hoover Dam.

<sup>b</sup> Exploitation rates for October 1992-August 1993 are minimum estimates since the creel survey did not start until September 1993. Exploitation rates were higher for fish stocked in Area 7 versus Area 6, July 1993-July 1994 (Mann-Whitney *U* test, *P* = 0.037).

<sup>c</sup> Total exploitation rate for September 1993-October 1995 only, the time of the creel survey.

-- Unknown

subsample, the entire 50 ml sample was counted. We identified zooplankton using the keys of Pennak (1989) and Thorp and Covich (1991). We estimated zooplankton density as the number of organisms/sample divided by the volume of water filtered. We did not include rotifers in our analysis because they are not effectively sampled with net mesh sizes  $>10\ \mu\text{m}$  (deBernardi 1984).

### Benthos

We collected benthos samples bimonthly from October 1993-December 1995, to determine densities, diversity, and distribution of aquatic invertebrates. At the Eldorado and Monkey Hole sites, we took 3 samples at random points along each transect with a Petite Ponar® Grab (grab; Wildlife Supply Company, Saginaw, Mich.;  $0.023\ \text{m}^2$  sample area), and rinsed them through a  $600\ \mu\text{m}$  mesh wash bucket. At the Ringbolt Rapids site, we collected 2 kicknet ( $0.203\ \text{m}^2$  sample area;  $800 \times 900\ \mu\text{m}$  mesh) samples along the Arizona shore, because substrates were too large to use the grab. We also collected 2 grab samples from a *Potamogeton* spp. bed just upstream from Ringbolt Rapids on the Nevada shore to determine if additional taxa occupied this aquatic macrophyte habitat. At the Hoover Dam site, 2 kicknet samples were taken from a gravel island immediately downstream from the restriction cable, near the Nevada shore. On some sample dates, the island was completely inundated and could not be safely or effectively sampled. Therefore, we collected additional grab samples within 500 m upstream or downstream of the restriction cable where substrates were small enough to sample. Benthos samples were preserved in 50% isopropanol. In the lab, we counted and identified organisms to Order or Family using keys of Pennak (1989) and Thorp and Covich (1991).

### Nutrients, Chlorophyll-*a*, and Physicochemical Variables

We measured water nutrient and chlorophyll-*a* concentrations to determine if these indicators of biological productivity have decreased since the 1970s. We collected 2-1 L water nutrient samples with a Kemmerer Bottle at random points along each site transect. We collected samples bimonthly from December 1993-December 1995 at Hoover Dam, from June 1994-December 1995 at Ringbolt Rapids, and from August 1993-December 1995 at Monkey Hole and

Eldorado. We collected samples from 1 m below the water surface, then immediately preserved each sample with 0.75 ml sulfuric acid. Samples were kept cold until analyzed. We analyzed samples for total phosphorus (4500-P C-5, E; APHA 1989), total nitrates and nitrites (4500-NO<sub>3</sub>, E; APHA 1989), total Kjeldahl nitrogen (4500-N A; APHA 1989), and ammonia (NH<sub>3</sub>-N; 4500-N F; APHA 1989). Minimum detection limits were 0.02 mg/l for total phosphorus, 0.05 mg/l for total nitrates and nitrites, 0.1 mg/l for total Kjeldahl nitrogen and 0.05 mg/l for ammonia. We analyzed October 1994-August 1995 total phosphorus samples with EPA method 365.3 (Environmental Protection Agency 1983) to obtain lower minimum detection limits (0.005 mg/l). We analyzed samples within 1 month after they were collected.

We collected 2 water samples bimonthly from February 1994-December 1995 at random points along each site transect for Chlorophyll-*a* analysis. Each sample was a composite of 3-1 L subsamples taken from 0 (surface), 5 m, and 10 m (or as close to 10 m as possible if the water depth was  $\geq 8$  m). If water depth was  $<8$  m, then subsample depths were 0, 3 m, and 5 m. Each composite sample was filtered in the field through a Whatman® GF/F glass fiber filter ( $0.7\ \mu\text{m}$ ). Filters were wrapped in foil and placed on ice, and kept frozen in the lab until analysis was done (APHA 1989).

We measured physicochemical variables bimonthly from August 1993-December 1995 to determine if they were within suitable limits for rainbow trout. We used a Horiba U-10 Water Quality Tester at mid channel of each sample site to measure pH, temperature (C), conductivity ( $\mu\text{S}/\text{cm}$ ), dissolved oxygen (mg/l) and salinity (%). Measurements were taken at 0, 5 m, and 10 m depths, or every meter if the water was thermally stratified.

### Hatchery Records

We reviewed WBNFH files from 1963-1995 to identify changes in hatchery sources of eggs or strains of rainbow trout stocked. We also investigated changes in sizes of fish stocked. Because the fishery began to decline in the late 1970s, we chose to compare the years 1963-1975 with 1976-1995.

### Relative Abundance of Fish Species

We used gill nets to survey the relative abundance of fish species inhabiting the tailwater. We sampled along the Arizona shore near Chalk

Cliffs (NV 43), and from Monkey Hole to Windy Canyon in July and August 1993, and April 1994 (Fig. 4). We used nets with 3.8 cm, 6.4 cm, and 7.6 cm mesh, and experimental nets with 1.3 to 5.1 cm and 2.5 to 8.9 cm mesh. We fished nets in shallow shoreline areas, and set them perpendicular to, and parallel to shore. The morphology of the riverbed (steep canyon wall banks and a deep channel), along with swift currents hindered netting in other tailwater areas.

### Statistical Analyses

We used a Mann-Whitney *U* test to compare exploitation rates of rainbow trout stocked in Area 6 versus Area 7, as data variances were unequal (Levene's test,  $P = 0.01$ ). To quantify predation on rainbow trout, we compared the numbers of rainbow trout found in large striped bass stomachs  $\leq 2$  weeks after stock dates, versus  $> 2$  weeks after stocking (Collis et al. 1995), with a Mann-Whitney *U* test (Levene's test,  $P < 0.01$ ). In addition, we used a Mann-Whitney *U* test (Levene's test,  $P < 0.01$ ) to compare rainbow trout numbers found in large striped bass stomachs during the ESA Section 7 no-stocking period (April-June 1994) versus the period when rainbow trout were stocked. We identified changes in large striped bass diet between the stocking and Section 7 no-stocking periods with 2 by 2 contingency table analyses using the chi-square statistic ( $\chi^2$ ).

We used the Schoener Index to determine diet overlap between rainbow trout and small striped bass (Whittaker and Fairbanks 1958, Schoener 1970). This index can be applied when the availability of the resource is unknown (Hurlbert 1978). The index ranges from 0 to 1, with 0 representing no overlap in resource use and 1 representing complete overlap. Index values  $\geq 0.6$  are considered to represent a biologically significant overlap of resource use (Zaret and Rand 1971, Mathur 1977). We also compared rainbow trout and small striped bass diets with a Spearman's rank correlation coefficient (Spearman's  $r$ ). This measurement is more objective than an overlap index because the significance of the correlation can be determined with a *t*-test. However, the correlation coefficient does not put sufficient weight on large amounts of overlap between 2 food items (Wallace 1981). We used the mean of the volume percentages of food items (the average percentage that each food category contributed to the total volume of food in each stomach) as a measure of diet, which is the

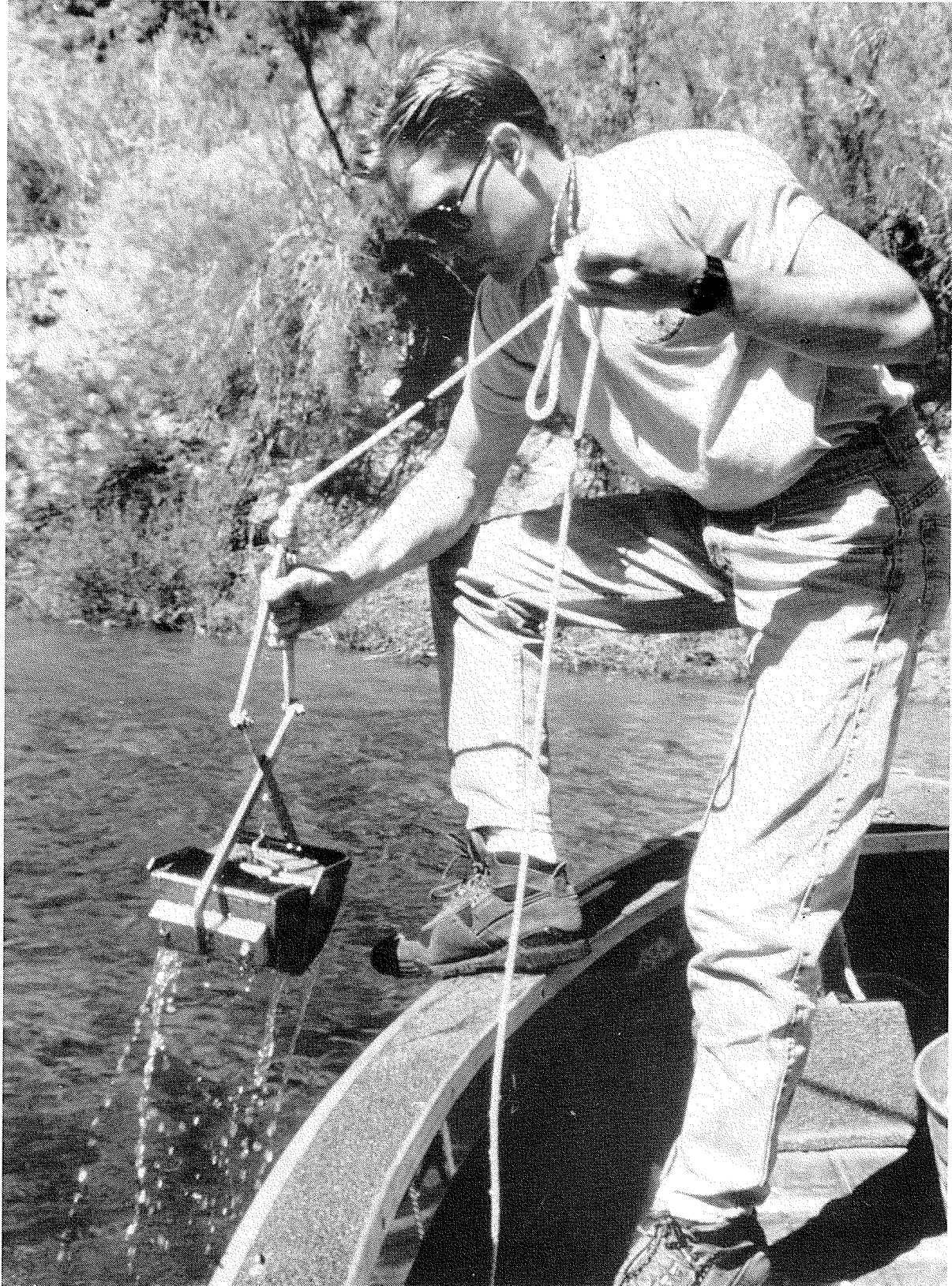
least biased measure for fish diets (Wallace 1981).

Zooplankton data did not meet analysis of variance (ANOVA) assumptions (Levene's test,  $P < 0.05$ ). Therefore, we used Kruskal-Wallis ANOVA and nonparametric multiple comparisons (Zar 1984, p. 199) to detect spatial and temporal differences in zooplankton densities.

Benthos data did not meet ANOVA assumptions (Levene's test,  $P < 0.05$ ), so we used a Kruskal-Wallis ANOVA to determine if data among years could be combined for each sampling gear. We could not use statistical tests to determine spatial differences among the 4 sampling sites due to biases associated with different sampling gears. Thus, we could only make qualitative comparisons of benthos densities among sites.

All statistical comparisons were considered significant at the  $P \leq 0.05$  level.





Sampling benthic invertebrates.





## RESULTS

### Rainbow Trout Exploitation and Survival

We interviewed 2,844 anglers and recovered 539 tagged rainbow trout through our creel survey. Tag retention of the 52 fish held in the hatchery raceway for 223 days was 96%. Thus, we feel tag loss did not affect our estimates of exploitation and survival. Yearly exploitation of all tagged rainbow trout was 2.6% (Table 2). Exploitation rates for individual cohorts of tagged rainbow trout ranged from 0 to 15% and were higher for fish stocked into Area 7 than in Area 6 ( $U = 19.5$ ,  $P = 0.037$ ; Table 2).

Eighty-three percent of the harvested rainbow trout were caught within 4 weeks after being stocked, with 62% caught within the first 2 weeks. Because only 17% of harvested rainbow trout remained in the tailwater more than a month after being stocked, sample sizes were too small to calculate growth rates. No tagged fish seen in our creel survey were harvested >320 days post-release. Therefore, stocked rainbow trout annual survival rates seem to approach 0.

No rainbow trout creeded in 1993 were  $\geq 508$  mm, while 2.4% ( $n = 9$ ) and 0.2% ( $n = 1$ ) of those creeded in 1994 and 1995 respectively, were  $\geq 508$  mm. None of these fish were tagged, but 2 fish harvested in 1994 were brood fish stocked in January 1994 (marked by an adipose fin clip). The largest rainbow trout creeded was 641 mm and weighed 4.13 kg.

### Striped Bass Predation

More rainbow trout were found in stomachs of large striped bass harvested  $\leq 2$  weeks after rainbow trout were stocked, compared with >2 weeks after stocking ( $U = 4328$ ;  $P = 0.008$ ). Also, large striped bass stomachs contained fewer rainbow trout during the ESA Section 7 no-stocking period (April-June 1994), compared with the period of stocking ( $U = 1,842$ ;  $P = 0.012$ ). During the ESA Section 7 no-stocking period, fewer large striped bass stomachs (non-empty) contained rainbow trout ( $\chi^2 = 19.81$ ,  $P < 0.001$ ), while more stomachs contained cladocera ( $\chi^2 = 10.04$ ,  $P = 0.002$ ), chironomid pupae ( $\chi^2 = 7.29$ ,  $P = 0.007$ ), and unidentifiable fish remains ( $\chi^2 = 4.55$ ,  $P = 0.033$ ; Table 3). The percentage of empty stomachs from large striped bass did not change between the stocking and no-stocking periods ( $\chi^2 = 1.94$ ,  $P = 0.163$ ).

### Rainbow Trout and Small Striped Bass Diet Overlap

The Schoener Index for rainbow trout and small striped bass was 0.51. Spearman's  $r$  was 0.4 ( $P = 0.059$ ). Chironomid pupae was the most dominant food group for both rainbow trout and small striped bass. Terrestrial insects and algae were consumed by rainbow trout but not by small striped bass (Table 4, Appendix A).

### Zooplankton

We collected and analyzed 109 zooplankton samples. Six zooplankton families were identified including 3 Cladocera (Chydoridae, Bosminidae, and Daphnidae) and 3 Copepoda (Calanoida, Cyclopoida, and Harpacticoida). Benthic organisms such as chironomids, nematodes, tardigrades, aquatic oligochaetes, and hydracarina were occasionally found in the zooplankton samples but were not included in the analyses.

Median zooplankton densities did not differ between 1994 and 1995 for each site. Therefore, data were combined across years for each site. Median zooplankton density in the tailwater was 1,775/m<sup>3</sup> (range = 134-35,681/m<sup>3</sup>) for all sites combined. Zooplankton densities did not change from Hoover Dam downstream to Monkey Hole ( $P = 0.376$ ). Densities at the 3 upstream sites ranged from 134-12,456/m<sup>3</sup>, with a median of 1,555/m<sup>3</sup> ( $n = 81$ ). Median densities were 1,996/m<sup>3</sup> (range = 366-11,918/m<sup>3</sup>;  $n = 27$ ) at Hoover Dam, 1,566/m<sup>3</sup> (range = 531-12,456/m<sup>3</sup>;  $n = 27$ ) at Ringbolt Rapids, and 1,453/m<sup>3</sup> (range = 134-8,165/m<sup>3</sup>;  $n = 27$ ) at Monkey Hole. At Eldorado, zooplankton density increased ( $P = 0.003$ ), ranging from 543-35,681/m<sup>3</sup>, with a median of 6,452/m<sup>3</sup> ( $n = 28$ ).

Adult and nauplii copepods composed 44.2% and 40.8% of all zooplankton sampled, respectively. Cladocerans composed 15.0% of all zooplankton sampled. Adult copepods comprised the highest percentage of zooplankton at Monkey Hole (48.9%) and nauplii made up the highest percentage at Ringbolt Rapids (57.3%). Cladocerans at Eldorado constituted more of the total zooplankton abundance (13.3%) than any other site.

A significant temporal difference in zooplankton densities (all sites combined) existed between years ( $P = 0.030$ ). Zooplankton densities were higher during June and August than all other months in both 1994 and 1995 ( $P < 0.05$ ; Table 5). Cladocera densities peaked during June in both years and were lowest in February and December in 1994 and 1995, respectively. During

Table 3. Occurrence of food items found in large ( $\geq 400$  mm) striped bass stomachs (with food) collected when rainbow trout were stocked ( $n=145$  stomachs<sup>a</sup>) versus a no-stocking period ( $n=19$  stomachs<sup>b</sup>).

Food item <sup>c</sup>	% of stomachs containing food item	% of total no. of food items	% of total volume of food items
Cladocera			
Stocking	3 <sup>d</sup>	5.1	0
No stocking	21	87.1	0.2
Crayfish ( <i>Procambarus clarki</i> )			
Stocking	4	0.3	0.8
No stocking	11	0.1	3.0
Chironomid larvae			
Stocking	8	5.1	0
No stocking	16	0.2	0
Chironomid pupae			
Stocking	33 <sup>d</sup>	78.4	0.1
No stocking	53	12.2	0.6
Rainbow trout			
Stocking	64 <sup>d</sup>	7.2	97.7
No stocking	11	0.1	93.5
Unidentifiable fish			
Stocking	10 <sup>d</sup>	0.6	0.7
No stocking	26	0.1	2.4

<sup>a</sup> An additional 78 stomachs were empty.

<sup>b</sup> An additional 5 stomachs were empty.

<sup>c</sup> Other food items (found in <10% of large striped bass stomachs) included: algae, aquatic macrophytes, copepods, amphipods, aquatic hemipterans, terrestrial insects, striped bass and *Leopomis* spp. Combined, these items made up 1.1% of the total number of food items and 0.8% of the total volume of food items.

<sup>d</sup>  $P \leq 0.05$  for stocking versus no stocking.

Table 4. Rainbow trout ( $n=142$  stomachs) and small ( $<400$  mm) striped bass ( $n=54$  stomachs) food items, Hoover Dam tailwater, July 1993-January 1995<sup>a</sup>. RBT = rainbow trout; STB = striped bass.

Food item	% of stomachs containing food item		% of total no. of food items		% of total volume of food items		Mean of volume % of food items <sup>b</sup>	
	RBT	STB	RBT	STB	RBT	STB	RBT	STB
Algae	26.1	1.9	0.1	<0.1	18.9	0.0	10.0	0.0
Aquatic macrophytes	43.7	9.3	0.2	0.1	29.7	1.6	11.6	5.6
Lumbricidae	1.4	0.0	<0.1	0.0	2.5	0.0	0.3	0.0
Cladocera	54.2	13.0	40.7	24.9	3.4	0.6	5.0	2.8
Copepoda	11.3	0.0	0.4	0.0	<0.1	0.0	0.0	0.0
Ostracoda	1.4	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0
<i>Hyallela azteca</i>	24.6	22.2	8.1	0.6	9.5	0.2	3.1	1.9
Unidentifiable Amphipoda	10.6	0.0	0.2	0.0	<0.1	0.0	0.0	0.0
<i>Procambarus clarki</i>	0.0	5.6	0.0	<0.1	0.0	37.4	0.0	5.6
Hydracarina	26.8	0.0	0.9	0.0	<0.1	0.0	0.0	0.0
Aquatic Hemiptera	14.8	1.9	1.9	<0.1	2.4	0.0	2.1	0.0
Chironomid larvae	56.3	22.2	1.9	3.2	<0.1	0.8	0.0	1.1
Chironomid pupae	84.5	81.5	44.1	70.7	23.2	54.7	18.8	37.1
Terrestrial Insecta	30.3	0.0	0.8	0.0	3.1	0.0	5.5	0.0
<i>Lymnaea</i> spp.	1.4	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0
<i>Physa</i> spp.	7.0	0.0	0.3	0.0	4.1	0.0	2.2	0.0
Planorbidae	1.4	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0
Unidentifiable Gastropoda	3.5	0.0	<0.1	0.0	0.2	0.0	0.3	0.0
<i>Corbicula fluminea</i>	1.4	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0
Rainbow trout	0.7	1.9	<0.1	<0.1	0.1	0.0	0.0	0.0
Striped bass	0.7	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0
Unidentifiable fish remains	9.2	7.4	0.1	0.4	2.9	4.7	1.6	5.3

<sup>a</sup> 3 additional rainbow trout stomachs and 16 additional striped bass stomachs were empty and not included in analyses.

<sup>b</sup> The average percentage that each food category contributed to the total volume of food in each stomach (Wallace 1981). The Schoener Index (Schoener 1970) = 0.51 and Spearman's  $r = 0.4$  ( $P = 0.059$ ) for diet overlap between rainbow trout and small striped bass.

Table 5. Monthly median zooplankton densities (number/m<sup>3</sup>), in the Hoover Dam tailwater, February 1994-December 1995. Ranges are in parentheses. June and August densities were higher than all other months in 1994 and 1995 ( $P \leq 0.05$ , Kruskal-Wallis ANOVA and nonparametric multiple comparison test).

Year	Month	<i>n</i>	Cladocera	Copepoda	Copepoda nauplii	All taxa
1994						
	Feb	9	23 (11-60)	780 (339-1,009)	872 (175-1,899)	1,799 (541-2,751)
	Apr	11	157 (55-541)	455 (199-575)	256 (25-695)	964 (315-1,427)
	Jun	13	342 (81-14,187)	1,597 (1,042-5,485)	4,841 (1,543-9,756)	8,165 (2,683-24,030)
	Aug	12	250 (118-19,167)	3,238 (1,946-7,431)	1,575 (589-9,082)	6,458 (2,949-35,681)
	Oct	8	31 (16-1,845)	727 (599-9,823)	868 (160-4,787)	1,563 (791-16,454)
	Dec	8	168 (69-472)	549 (295-952)	413 (321-501)	1,129 (684-1,775)
1995						
	Feb	8	177 (83-323)	446 (98-1,032)	329 (52-588)	957 (251-1,943)
	Apr	8	103 (63-178)	584 (364-1,097)	821 (445-2,364)	1,616 (916-3,560)
	Jun	8	140 (50-10,531)	1,297 (505-12,643)	1,309 (398-2,989)	2,678 (1,034-26,163)
	Aug	8	95 (46-12,354)	2,252 (1,525-3,382)	1,997 (1,717-3,670)	4,716 (3,311-19,406)
	Oct	8	116 (40-2,560)	561 (370-4,868)	692 (331-6,525)	1,336 (744-13,952)
	Dec	8	44 (15-113)	355 (84-545)	142 (36-320)	571 (134-978)



1994, adult copepod density was highest during August and nauplii density was highest during June. In 1995, copepod adults and nauplii were most abundant during August. Copepod adult and nauplii densities were lowest in April 1994 and December 1995.

### Benthos

No significant differences in benthic organism densities existed among 1993, 1994, and 1995 for data collected with the grab ( $P = 0.254$ ) or kicknet ( $P = 0.844$ ). In addition, no difference in the median number of organisms collected in the *Potamogeton* spp. bed with a grab existed between 1994 and 1995 ( $P = 0.895$ ). Therefore, yearly data were combined for each sampling gear.

The benthic community included members of 7 classes: Insecta (Chironomidae), Oligochaeta (Tubificidae and Lumbricidae), Malacostraca (*Hyallela azteca*), Gastropoda (*Physa* spp. and *Lymnaea* spp.), Bivalvia (*Corbicula fluminea*), Turbellaria, and Arachnida (Hydracarina). Chironomids were typically the most abundant benthic organisms collected in the *Potamogeton* spp. bed (Table 6) and in the kicknet samples (Table 7). Oligochaetes (Tubificidae and Lumbricidae) and chironomids usually dominated the grab samples (Table 8). *H. azteca* abundance was highest at Hoover Dam and Ringbolt Rapids.

### Nutrients, Chlorophyll-*a*, and Physicochemical Variables

The highest total phosphorus concentration we measured was 0.24 mg/l at Ringbolt Rapids. However, total phosphorus concentrations were often below minimum detection limits of 0.005 mg/l. Total nitrate-nitrite concentrations ranged from 0.144 mg/l (Eldorado) to 0.450 mg/l (Hoover Dam). Total Kjeldahl nitrogen concentrations ranged from 0.132 mg/l to 0.317 mg/l (both at Eldorado). Ammonia concentrations were always below the 0.05 mg/l minimum detection limit. Chlorophyll-*a* concentrations ranged from 0.05 mg/l (Hoover Dam) to 3.34 mg/l (Eldorado). Ranges of water nutrient and chlorophyll-*a* concentration measurements are summarized in Table 9, along with concentrations reported in earlier studies on the tailwater. Median nutrient and chlorophyll-*a* values are given in Appendix B. Physicochemical variable measurements are summarized in Table 10 and Appendix C.

### Hatchery Records

Willow Beach National Fish Hatchery received eggs from 22 sources from 1962-1975, and from 17 sources from 1976-1995 (Appendix D). However, before 1978, individual strains of rainbow trout raised at WBNFH were not consistently recorded. Only the DeSmet and Hot Creek strains were documented from 1962-1975. From 1976-1995, 12 individual strains were recorded (Table 11). The Erwin strain of rainbow trout was most commonly stocked by WBNFH.

Willow Beach National Fish Hatchery stocked catchable (203 mm) size rainbow trout from 1963-1973. However, 1974-1978 stockings were mainly subcatchable (101-152 mm) fish. Fish stocked from 1979-1987 averaged 203 mm, and those stocked from 1988-1995 averaged 229 mm.

### Relative Abundance of Fish Species

We caught 87 common carp, 38 razorback suckers, 20 striped bass, 14 channel catfish, and 8 rainbow trout with gill nets.

Table 6. Median catch per unit effort of benthic organisms collected with a grab (number/grab) in the *Potamogeton* spp. bed just upstream from Ringbolt Rapids, Hoover Dam tailwater, February 1994-December 1995. TUR=Turbellaria, TUB=Tubificidae, LUM=Lumbricidae, HYA=*Hyallela azteca*, HYD=Hydracarina, CHL=Chironomidae larvae, CHP=Chironomidae pupae, PHY=Physidae. Ranges are in parentheses.

Month	<i>n</i>	TUR	TUB	LUM	HYA	HYD	CHL	CHP	PHY	All taxa
Feb	4	10 (0-55)	0 (0-1)	0 (0-0)	1 (0-23)	1 (0-4)	308 (28-453)	11 (1-43)	0 (0-5)	332 (30-579)
Apr	4	15 (0-65)	0 (0-0)	5 (0-29)	7 (3-18)	2 (0-5)	1,270 (212-2,432)	78 (10-257)	0 (0-8)	1,478 (255-2,579)
Jun	4	1 (0-2)	0 (0-1)	0 (0-0)	8 (5-15)	8 (0-27)	1,573 (1,078-1,868)	137 (57-215)	2 (0-4)	1,761 (1,142-2,064)
Aug	3	8 (6-9)	0 (0-391)	23 (0-69)	31 (12-165)	4 (1-7)	26 (25-381)	5 (1-6)	0 (0-0)	143 (75-952)
Oct	3	32 (19-61)	0 (0-209)	0 (0-0)	117 (23-881)	8 (4-18)	17 (5-18)	3 (2-3)	1 (1-19)	426 (59-956)
Dec	4	1 (0-25)	0 (0-0)	2 (0-7)	43 (6-132)	0 (0-6)	300 (50-623)	38 (5-66)	2 (0-4)	420 (72-784)

Table 7. Monthly median benthos densities (number/m<sup>2</sup>) collected with a kicknet at Ringbolt Rapids (RR) and Hoover Dam (HD), Hoover Dam tailwater, October 1993 to December 1995. TUR = Turbellaria, TUB = Tubificidae, LUM = Lumbricidae, HYA = *Hyallala azteca*, HYD = Hydracarina, CHI = Chironomidae, PHY = Physidae, LYM = *Lymnaea* spp., COR = *Corbicula fluminea*. Ranges are in parentheses.

Month	Site	n	TUR	TUB	LUM	HYA	HYD	CHI	PHY	LYM	COR	All taxa
Feb	RR	4	25 (0 - 227)	0 (0 - 0)	7 (0 - 404)	12 (0 - 74)	3 (0 - 20)	259 (49 - 1,429)	0 (0 - 5)	0 (0 - 0)	0 (0 - 0)	305 (49 - 2,158)
	HD	4	10 (5 - 212)	0 (0 - 0)	145 (113 - 163)	25 (5 - 74)	5 (0 - 10)	411 (153 - 1,241)	25 (5 - 49)	3 (0 - 25)	0 (0 - 0)	616 (315 - 1,754)
Apr	RR	4	0 (0 - 25)	0 (0 - 0)	25 (0 - 49)	3 (0 - 10)	0 (0 - 5)	148 (30 - 2,128)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	168 (49 - 2,212)
	HD	2	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	5 (5 - 5)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	5 (5 - 5)
Jun	RR	4	0 (0 - 49)	10 (0 - 39)	0 (0 - 15)	552 (5 - 2,443)	123 (0 - 330)	860 (64 - 2,035)	3 (0 - 39)	0 (0 - 0)	0 (0 - 0)	1,786 (74 - 4,468)
	HD	2	0 (0 - 0)	0 (0 - 0)	27 (5 - 49)	256 (172 - 340)	7 (0 - 15)	495 (468 - 522)	25 (20 - 30)	0 (0 - 0)	0 (0 - 0)	810 (773 - 847)
Aug	RR	4	0 (0 - 0)	0 (0 - 0)	3 (0 - 20)	5 (0 - 15)	0 (0 - 0)	0 (0 - 5)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	12 (0 - 30)
	HD	2	22 (20 - 25)	0 (0 - 0)	54 (44 - 64)	202 (133 - 271)	10 (5 - 15)	121 (118 - 123)	145 (113 - 177)	7 (5 - 10)	0 (0 - 0)	562 (503 - 621)
Oct	RR	6	9 (0 - 89)	0 (0 - 0)	37 (0 - 148)	49 (0 - 226)	0 (0 - 27)	12 (0 - 1,895)	17 (0 - 30)	0 (0 - 0)	0 (0 - 5)	197 (74 - 232)
	HD	4	27 (0 - 94)	0 (0 - 15)	170 (133 - 276)	5 (0 - 25)	0 (0 - 5)	254 (0 - 833)	89 (20 - 108)	17 (0 - 89)	0 (0 - 0)	603 (266 - 1,246)
Dec	RR	4	5 (0 - 10)	0 (0 - 0)	30 (0 - 54)	10 (0 - 15)	0 (0 - 5)	39 (5 - 64)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	76 (25 - 143)
	HD	6	0 (0 - 10)	0 (0 - 0)	81 (19 - 301)	10 (0 - 39)	0 (0 - 5)	3 (0 - 15)	1 (0 - 35)	5 (0 - 35)	0 (0 - 0)	209 (84 - 379)

Table 8. Median benthos densities (number/m<sup>2</sup>) collected with a grab at Eldorado (EL), Monkey Hole (MH), and Hoover Dam (HD), Hoover Dam tailwater, October 1993 to December 1995. TUR = Turbellaria, TUB = Tubificidae, LUM = Lumbricidae, HYA = *Hyallela azteca*, HYD = Hydracarina, CHI = Chironomidae, PHY = Physidae, LYM = *Lymnaea* spp., COR = *Corbicula fluminea*. Ranges are in parentheses.

Month	Site	n	TUR	TUB	LUM	HYA	HYD	CHI	PHY	LYM	COR	All taxa
Feb												
	EL	7	0 (0-0)	87 (0-435)	0 (0-0)	0 (0-0)	0 (0-0)	391 (0-826)	0 (0-0)	0 (0-0)	0 (0-87)	478 (261-826)
	MH	6	0 (0-87)	413 (0-1,826)	0 (0-0)	0 (0-0)	0 (0-0)	174 (87-696)	0 (0-43)	0 (0-0)	0 (0-0)	696 (174-2,609)
	HD	2	87 (0-174)	0 (0-0)	65 (0-130)	217 (174-261)	43 (0-87)	1,652 (348-2,957)	152 (43-261)	0 (0-0)	0 (0-0)	2,217 (1,174-3,261)
Apr												
	EL	6	0 (0-174)	261 (0-783)	0 (0-0)	0 (0-0)	0 (0-43)	217 (130-435)	0 (0-0)	0 (0-0)	0 (0-0)	609 (304-1,087)
	MH	6	0 (0-0)	652 (87-1,696)	0 (0-0)	0 (0-43)	0 (0-0)	435 (0-1,478)	0 (0-43)	0 (0-0)	0 (0-43)	1,022 (174-3,217)
	HD	5	0 (0-348)	0 (0-43)	0 (0-304)	0 (0-87)	0 (0-348)	522 (43-1,696)	0 (0-130)	0 (0-87)	0 (0-0)	783 (87-1,913)
Jun												
	EL	6	0 (0-0)	413 (0-2,087)	0 (0-0)	0 (0-0)	0 (0-43)	65 (0-348)	0 (0-43)	0 (0-0)	0 (0-0)	674 (0-2,130)
	MH	6	0 (0-43)	304 (0-1,130)	0 (0-0)	0 (0-43)	0 (0-0)	565 (87-1,217)	0 (0-130)	0 (0-0)	0 (0-0)	1,044 (87-2,391)
	HD	5	0 (0-130)	0 (0-0)	0 (0-0)	87 (0-6,652)	43 (0-87)	43 (43-8,261)	174 (0-261)	0 (0-0)	0 (0-0)	391 (261-15,261)

Table 8. (continued)

Month Site	n	TUR	TUB	LUM	HYA	HYD	CHI	PHY	LYM	COR	All taxa
Aug											
EL	6	0 (0-0)	326 (0-1,087)	0 (0-0)	0 (0-0)	0 (0-0)	348 (0-652)	0 (0-0)	0 (0-0)	0 (0-43)	652 (391-1,391)
MH	6	0 (0-0)	217 (0-4,478)	0 (0-2,913)	0 (0-0)	22 (0-43)	804 (0-1,696)	0 (0-87)	0 (0-0)	0 (0-0)	3,044 (0-5,217)
HD	5	0 (0-87)	0 (0-43)	43 (0-1,000)	43 (0-130)	0 (0-217)	43 (0-174)	0 (0-130)	0 (0-43)	0 (0-0)	304 (87-1,435)
Oct											
EL	8	0 (0-43)	261 (0-1,174)	0 (0-0)	0 (0-174)	0 (0-87)	130 (0-870)	0 (0-0)	0 (0-0)	0 (0-87)	717 (174-2,044)
MH	8	0 (0-43)	826 (87-7,565)	0 (0-0)	22 (0-435)	0 (0-130)	217 (130-478)	0 (0-0)	0 (0-0)	0 (0-0)	1,826 (478-8,304)
HD	4	109 (0-739)	0 (0-174)	0 (0-261)	239 (0-7,739)	0 (0-435)	0 (0-87)	0 (0-43)	0 (0-0)	0 (0-43)	652 (0-8,913)
Dec											
EL	8	0 (0-43)	674 (43-1,174)	0 (0-0)	0 (0-43)	0 (0-43)	130 (0-478)	0 (0-0)	0 (0-0)	0 (0-130)	913 (261-1,783)
MH	8	0 (0-43)	804 (435-4,739)	0 (0-0)	0 (0-0)	0 (0-130)	370 (174-1,174)	0 (0-0)	0 (0-0)	0 (0-0)	2,217 (652-4,913)
HD	4	543 (0-1,174)	0 (0-43)	0 (0-87)	391 (0-870)	0 (0-0)	391 (0-826)	43 (0-174)	0 (0-0)	0 (0-0)	1,478 (44-2,913)



Table 9. Range of values for nutrient and chlorophyll-*a* concentrations reported for the Hoover Dam tailwater.

Sample site	Year	Total phosphorus (mg/l)	NO <sub>2</sub> + NO <sub>3</sub> (mg/l)	Dissolved inorganic N <sup>a</sup> (mg/l)	Total Kjeldahl N (mg/l)	Chlorophyll- <i>a</i> (mg/m <sup>3</sup> )	Reference
Hoover Dam	1935-1943		2.6-3.3 <sup>b</sup>				Jonez and Sumner (1954)
	1971-1975		0.30-1.1 <sup>c</sup>				U.S. Geol. Survey, unpubl. data
	1976-1980	<0.01-0.31	0.28-0.55 <sup>c</sup>		<0.01-2.4		U.S. Geol. Survey, unpubl. data
	1993-1995	<0.005-0.020	0.340-0.450		0.156-0.266	0.05-0.48	Present study
Ringbolt Rapids	1993-1995	<0.005-0.024	0.328-0.432		0.182-0.276	0.19-1.55	Present study
Monkey Hole	1976-1977	0.018-0.038 <sup>d</sup>		0.360-0.490 <sup>c</sup>	0.140-0.930 <sup>c</sup>		Priscu et al. (1982)
	1977-1978	0.008-0.019 <sup>g</sup>	0.025-0.370 <sup>g</sup>			0.1-2.0	Paulson et al. (1980a)
	1993-1995	<0.005-0.020	0.323-0.410		0.164-0.297	0.08-1.01	Present study
Eldorado	1976-1977	0.02-0.12 <sup>d</sup>		0.03-0.420 <sup>c</sup>	0.185-0.980 <sup>c</sup>	1.0-26.4	Priscu et al. (1982)
	1977-1978	0.005-0.030 <sup>h,i</sup>	0.09-0.350 <sup>h</sup>			0.2-49.6	Paulson et al. (1980a)
	1993-1995	<0.005-0.023	0.144-0.381		0.132-0.317	0.24-3.34	Present study

<sup>a</sup> [(NO<sub>3</sub><sup>-</sup> + NO<sub>2</sub><sup>-</sup> + NH<sub>4</sub><sup>+</sup>) N].<sup>b</sup> NO<sub>3</sub> only; 1935-1939 samples taken at Willow Beach.<sup>c</sup> Dissolved NO<sub>2</sub> + NO<sub>3</sub>.<sup>d</sup> Estimated from Priscu et al. (1982), Figure 8.<sup>e</sup> Estimated from Priscu et al. (1982), Figure 9.<sup>f</sup> Dissolved phosphorus.<sup>g</sup> Estimated from Paulson et al. (1980a), Figure 4.4.1.<sup>h</sup> Estimated from Paulson et al. (1980a), Figure 4.7.4.

Table 10. Ranges of physicochemical values measured every other month in the Hoover Dam tailwater, October 1993-December 1995.

Site	pH	Conductivity ( $\mu$ S/cm)	Dissolved Oxygen (mg/l)	Temperature (C)	Salinity (%)
Hoover Dam	6.94-9.00	0.84-1.19	5.77-8.83	11.9-14.2	0.03-0.05
Ringbolt Rapids	7.05-8.05	0.83-1.19	6.50-9.28	12.2-14.7	0.03-0.05
Monkey Hole	7.14-8.09	1.07-1.21	6.05-9.41	11.9-15.5	0.04-0.05
Eldorado	7.40-8.25	0.84-1.23	7.26-10.03	11.6-28.4	0.03-0.05

Table 11. Documented rainbow trout strains stocked by Willow Beach National Fish Hatchery, 1962-1995.

Strain	1962-1975	1976-1995	% use of strain
Bel-Aire		X	11.33
De Smet	X	X	1.66
Eagle Lake		X	10.00
Erwin		X	38.66
Fish Lake x De Smet		X	2.66
Hot Creek	X		1.33
Kamloops		X	0.66
New Zealand		X	0.33
Soap Lake		X	0.66
Tasmanian		X	22.66
Wigwam		X	0.66
Wythville		X	7.33
Wythville x Erwin		X	2.06



## DISCUSSION

### Rainbow Trout Exploitation and Survival

Currently, overexploitation is not a factor limiting survival of rainbow trout stocked in the Hoover Dam tailwater. Exploitation rates we measured are generally lower than those reported for western tailwaters that supported quality rainbow trout fisheries (Table 12). However, fishing pressure and angling exploitation may be lower on the Hoover Dam tailwater than they were prior to our study. The concessionaire at Willow Beach ceased operation in January 1994, making boat slips and other services unavailable. Some anglers thought the public boat launch was closed as well. A new concessionaire began providing limited services (bait, fuel, ice) in February 1994, but the marina remained closed. In addition, stocking was halted for a 3-month period that spring, discouraging anglers from fishing at Willow Beach. Creel returns have been positively correlated with angling pressure in other waters (Rohrer 1987, Wiley et al. 1993).

Overexploitation may have affected the rainbow trout fishery in the 1980s. Exploitation rates of 103, 105, 82, and 101% were reported for the years 1980-1983, respectively (Nev. Div. of Wildl., unpubl. data). Thus, few fish would have been available to recruit to trophy size.

Annual survival of fish stocked into the Hoover Dam tailwater is near 0, suggesting that mortality limits survival in this system. However, rainbow trout (untagged)  $\geq 508$  mm were checked

in our creel survey, indicating that some fish do survive more than 1 year after being stocked. These fish are evidence that the food base is sufficient to produce trophy rainbow trout, but we do not know what density of trophy fish the tailwater could support.

### Striped Bass Predation

Striped bass predation currently limits the potential for a trophy rainbow trout fishery in the Hoover Dam tailwater. Stocked rainbow trout are the main prey item of striped bass. When rainbow trout stocking ceased from April-June 1994, striped bass soon depleted the population of fish stocked before April 1994. Large striped bass then switched to chironomid pupae as their main prey.

The decreased number of rainbow trout found in striped bass harvested  $>2$  weeks after stockings also indicates that predation can immediately deplete the stocked rainbow trout population. High mortality due to predation leaves fewer rainbow trout for anglers until the next stock date. Similar to our findings, Deppert and Mense (1979) found that stocked rainbow trout made up 40% (by number) of the striped bass diet within 1 week after the fish were stocked in the Illinois River, Oklahoma. They found no evidence for striped bass predation 1 week after stocking. They also concluded that striped bass predation was the reason creel returns of stocked rainbow trout were relatively low at 1 of their stocking sites.

Table 12. Exploitation rates of rainbow trout from western U.S. tailwaters.

Tailwater	Exploitation rate	Reference
Fontenelle Dam Green River, Wyo.	0.12	Wiley and Dufek (1980)
Glen Canyon Dam Colorado River, Ariz.	0.47 0.12 0.38	Stone (1966) Stone and Rathbun (1969) Persons et al. (1985)
Hoover Dam Colorado River, Ariz.-Nev.	0.16 0.15 - 1.05 0.03	Ariz. Game and Fish Dep. (unpubl. data [1968]) Nev. Dep. of Wildl. (unpubl. data [1980-92]) Present study
Navajo Dam San Juan River, N.M.	0.52 - 0.70	Mullan et al. (1976)

Piscivorous birds also prey on rainbow trout stocked into the Hoover Dam tailwater (L. Miller, Willow Beach Nat. Fish Hatchery, pers. commun.). Jonez and Sumner (1954) found trout in less than 2% of the 200 double-crested cormorant (*Phalacrocorax auritus*) and 23 great blue heron (*Ardea herodias*) stomachs they examined from the Hoover Dam tailwater area. However, these birds may have since adapted to preying on the regular supply of stocked fish. In Utah for example, double-crested cormorants have expanded their range and numbers since 1973 when they were associated with only 2 lakes (Ottenbacher et al. 1994). During 1989-91, double-crested cormorants preyed on stocked rainbow trout in 11 of 13 Utah reservoirs surveyed (Ottenbacher et al. 1994). In addition, Modde et al. (1996) determined that double-crested cormorants removed more trout from Minersville Reservoir, Utah, than did anglers. The lack of forage fish in the Hoover Dam tailwater suggests that rainbow trout are the main prey of piscivorous birds, but further research is needed to quantify this predation.

#### Rainbow Trout and Small Striped Bass Diet Overlap

Schoener's Index and Spearman's rank correlation suggest that rainbow trout and small striped bass diets overlapped little. However, chironomid pupae are the most utilized food item by both species. Therefore, a substantial decrease of chironomids could limit availability of this shared food resource and create a competitive situation. A more intensive study of food use and availability would be needed to address any potential competition between rainbow trout and small striped bass.

Two historically important food items are now infrequent in the rainbow trout diet. Threadfin shad were an important prey item after their introduction into Lake Mohave in 1955 (Trelease 1956, Nev. Div. of Wildl., unpubl. data). In addition, threadfin shad may have passed through Hoover Dam from Lake Mead (B. Silvey, Ariz. Game and Fish Dep., pers. commun.). Threadfin shad are also an important rainbow trout forage species in Lake Mead and other waters (Kirkland and Bowling 1966, Deacon et al. 1972, May et al. 1975, Weiland 1994). By the 1980s, before a striped bass population was established, threadfin shad became less important as rainbow trout forage in the Hoover Dam tailwater and Lake Mohave, apparently due to their declining numbers (T. Liles, Ariz. Game and

Fish Dep., pers. commun., Nev. Div. of Wildl., unpubl. data). We found no threadfin shad in the rainbow trout stomachs we examined.

Amphipods were an important rainbow trout food item below Hoover Dam in the 1950s (Jonez and Sumner 1954). Currently, amphipods are consumed less frequently, probably because population numbers have declined. In Lake Taneycomo, Missouri, rainbow trout growth decreased with a change from an amphipod and isopod dominated diet, to one dominated by chironomids, zooplankton and algae (Weiland 1994).

The decrease in threadfin shad and amphipods available in the Hoover Dam tailwater has probably contributed to lower rainbow trout growth rates. Thus, a trophy fishery may now be less attainable, even if striped bass predation was not a factor.

#### Zooplankton

Zooplankton densities in the Hoover Dam tailwater have decreased since 1978 (Paulson et al. 1980a). Maximum zooplankton densities we measured were lower than the mean densities of 23,000 and 178,000/m<sup>3</sup> reported by Paulson et al. (1980a) for Monkey Hole and Eldorado, respectively. Zooplankton production in the Hoover Dam tailwater appears limited when compared with other cold tailwaters (Table 13).

Rainbow trout are known to feed primarily on daphnids and can negatively influence the abundance and size of cladocerans available (Swift 1970, Varley 1979, Lynott 1995, but see Taylor and Gerking 1985). Because cladocerans are a rainbow trout prey item in the Hoover Dam tailwater, their decreased numbers may now limit growth compared with 20-30 years ago.

Lake Mead is the main source of zooplankton for the Hoover Dam tailwater. Zooplankton densities did not increase from Hoover Dam downstream to Monkey Hole, showing that little recruitment occurs within the tailwater, except downstream at Eldorado. Several sources of mortality can cause a decreasing trend in downstream zooplankton abundance, including predation, turbulence, suspended sediments, and entanglement with periphytic algae (Mohrgraby 1977, Walburg et al. 1981, Matter et al. 1983). Because we did not observe this trend in the Hoover Dam tailwater, some zooplankton recruitment may occur, balancing sources of mortality.

Evaluating the spatial and temporal patterns of zooplankton abundance can aid in setting stocking



Table 13. Mean zooplankton densities in tailwaters below hypolimnetic discharge dams.

Tailwater	Density (number/m <sup>3</sup> )	Reference
Hoover Dam, Ariz.	23,000 - 178,000	Paulson et al. (1980a)
Glen Canyon Dam, Ariz. (Glen Canyon)	4,290 - 23,151	Ayers and McKinney (1996)
Glen Canyon Dam, Ariz. (Grand Canyon)	4,000 - 64,000	Ariz. Game and Fish Dep. (unpubl. data)
Garrison Dam, N.D.	33,100 - 40,300	Speas (1995)
Fort Randall Dam, S.D.	12,870	Martin and Novotny (1977)

levels of planktivores. It can also aid in predicting when and where fingerling game fish should be stocked so that survivorship is not limited by food shortages (Speas 1995). Zooplankton abundance in the Hoover Dam tailwater increased significantly between Monkey Hole and Eldorado. A similar increase between these sites was also observed by Paulson et al. (1980a) and Jonez and Sumner (1954). The increase in zooplankton abundance at the Eldorado site may be due to increased nutrients and chlorophyll-*a* levels (thereby increasing food resources), and also more favorable water temperatures and lower flows in the more lacustrine-like environment (Marzolf 1990, Wetzel 1990).

Daphnid abundance peaked during June and August in both 1994 and 1995, which differed from the March through May peak observed in 1978 (Paulson et al. 1980a). The reason for this shift in peak abundance is unknown, but Hrbacek et al. (1961) presented evidence that introduced fish stocks can change the composition of plankton species through selective predation. The decline of threadfin shad as a primary zooplankton predator and the introduction of striped bass may be factors contributing to this shift.

### Benthos

Benthic diversity in the Hoover Dam tailwater has decreased since Lake Mohave formed in 1951, but has changed little since the 1970s. Ephemeropterans, trichopterans, odonates, chironomids, and coleopterans were all reported from the tailwater and from rainbow trout stomachs before 1951 (Moffett 1942, Jonez and Sumner 1954). By 1979, chironomids were the only benthic aquatic insect in the tailwater

(Paulson et al. 1980b). Similar to Paulson et al. (1980b), we collected mainly chironomids, oligochaetes, and amphipods, which are the dominant taxa in other tailwaters as well (Pfister 1954, Blanz et al. 1969, Ward 1974).

The amphipod *Gammarus lacustris* was once an important rainbow trout food item, but may now be extirpated from the Hoover Dam tailwater. *G. lacustris* was planted in the tailwater in 1941, and became prevalent in rainbow trout stomachs taken near Willow Beach in 1951 (Moffett 1942, Jonez and Sumner 1954). By 1979, *G. lacustris* was rare in the tailwater (Paulson et al. 1980b). We did not collect *G. lacustris* during our study. The disappearance of *G. lacustris* may be a result of predation (e.g., from rainbow trout), a lack of an adequate food source, or the inability to resist current (Ward 1976, Thorp and Covich 1991). *H. azteca* may be maintaining their populations in the Hoover Dam tailwater due to their ability to produce multiple broods (Strong 1972).

Benthic organism abundance in the Hoover Dam tailwater appears to have changed little since 1979. However, we could not make quantitative comparisons with data from Paulson et al. (1980b) because they used different sampling methods, reported mean densities, and often presented their results in graphs only. Mean benthic organism densities reported for other cold tailwaters are shown in Table 14.

Benthic organism distribution within the Hoover Dam tailwater remains similar to that reported for 1979 (Paulson et al. 1980b). Chironomid and *H. azteca* densities decreased at downstream sites, while oligochaetes showed an increasing trend at downstream sites during our study.

Table 14. Ranges of mean benthos densities in tailwaters.

Location	Mean Benthos Density (number/m <sup>2</sup> )	Reference
Eldorado Hoover Dam Tailwater Ariz.-Nev.	544 - 981	Paulson et al. (1980b)
Glen Canyon Dam Tailwater Ariz.	3,545 - 6,923	Ariz. Game and Fish Dep. (unpubl. data)
Tims Ford Dam Tailwater Tenn.	154 - 15,254	Clover (1993)
Navajo Dam Tailwater New Mex.	829 - 6,728	Mullan et al. (1976)

### Nutrients, Chlorophyll-*a*, and Physicochemical Variables

Nutrient availability and primary production in the Hoover Dam tailwater appear to have decreased since the 1970s, which may now limit rainbow trout growth. Our maximum total phosphorus, total Kjeldahl nitrogen, and chlorophyll-*a* levels were lower than those measured in 1976-77 (Paulson et al. 1980a, Priscu et al. 1982; Table 9). However, the Glen Canyon Dam tailwater has supported a sporadic trophy rainbow trout fishery, but nutrient levels are no higher than in the Hoover Dam tailwater. Ranges of 0.004-0.024 mg/l for total phosphorus, 0.147-0.419 mg/l for total nitrate-nitrite, and <0.005-0.4 mg/l for ammonia concentrations are reported for Lee's Ferry (Glen Canyon Dam tailwater) (Maddux et al. 1987, Reger et al. 1995, Ariz. Game and Fish Dep., unpubl. data). Qualitative observations also suggest that the Hoover Dam tailwater supported more filamentous algae and aquatic macrophytes in the 1970s than it does now (P. Mullane, U. S. Fish and Wildl. Serv., pers. commun., T. Liles, Ariz. Game and Fish Dep., pers. commun.).

Decreased nutrient availability probably did not contribute to the initial decline of the rainbow trout fishery. Priscu et al. (1982) reported that 1976-77 phytoplankton production in Lake Mohave was among the highest of freshwater systems ever studied. They attributed this productivity to the high nutrient levels in the Hoover Dam discharge (Priscu et al. 1982). Thus, nutrient levels and primary productivity probably

did not limit biological productivity and rainbow trout growth and survival in the 1970s.

The physicochemical variables we measured (pH, dissolved oxygen, temperature, and salinity) were all within ranges reported suitable for rainbow trout growth and survival (Alabaster and Lloyd 1980, Piper et al. 1989). Thus, the physicochemical makeup of the Hoover Dam tailwater does not limit the rainbow trout fishery.

A more intensive investigation of nutrient cycling and its link to biological production and rainbow trout growth would be needed to determine if the Hoover Dam tailwater can still support a trophy fishery. Such an intensive study will not be possible until survival rates of stocked rainbow trout can be improved, allowing for growth rate measurements.

### Hatchery Records

Because hatchery strain records were incomplete, we could not determine if changes in strain use affected the rainbow trout fishery. In addition, the performance of individual rainbow trout strains stocked by WBNFH was never evaluated. A single strain could have accounted for most of the trophy size fish harvested from the Hoover Dam tailwater in the 1960s and early 1970s, but we have no data to support this hypothesis. Davis (1992) concluded that the Eagle Lake and Kamloops rainbow trout strains have the necessary qualities (e.g., low susceptibility to anglers, fast growth) to achieve trophy status in the Colorado River. However, Davis (1992) did not report the susceptibility of either strain to predation.

Subcatchable rainbow trout were stocked by WBNFH from 1973-1977. Survival and growth of these subcatchables may have been lower than that of catchable size fish stocked before 1973 (Needham 1959, Cresswell 1981, Wiley et al. 1993). Subsequently, the number of trophy rainbow trout available to anglers may have decreased, due to poor recruitment of the subcatchable size fish.

### Relative Abundance of Fish Species

Fish species composition in the Hoover Dam tailwater has changed since the creation of Lake Mohave, though common carp are still the most predominant species, as they were in the 1950s (Jones and Sumner 1954). Black bullhead (*Amerius melas*), bonytail chub, Colorado River squawfish (*Ptychocheilus lucius*), dusky mountain sucker (desert sucker; *Catostomus clarki*), and flannelmouth sucker (*Catostomus latipinnis*) were all collected in the 1950s (Jones and Sumner 1954). We also did not collect threadfin shad, largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), or bluegill (*L. macrochirus*), which are known to frequent the downstream portion of Area 6 (M. Burrell, Nev. Div. of Wildl., pers. commun.). The change in fish species diversity since the 1950s is probably due to large scale riverine habitat alterations from Colorado River impoundments. While creating new lake habitats, these impoundments have reduced or eliminated spawning habitat for most of the native fishes and some introduced species.

### CONCLUSIONS

A lack of rainbow trout exploitation, survival, and diet data from the peak period of this fishery makes it difficult to determine why the fishery declined. We hypothesize that, beginning in the 1970s, the rainbow trout population suffered lower survival and growth rates, followed by high angler exploitation rates, and finally high predation rates. The threadfin shad forage base apparently began declining in the 1970s, which may have contributed to slower rainbow trout growth rates. In addition, survival of subcatchable size rainbow trout stocked from 1973-1977 may have been inadequate to support a trophy fishery, compared with the catchable size fish stocked previously. High angling exploitation rates then occurred from 1980-1983. Finally, the establishment of striped bass in Lake Mohave by the mid 1980s continued to affect the rainbow

trout population through predation. The population never recovered from this series of detrimental effects and, therefore, the tailwater no longer supports a trophy fishery.

We believe that a decrease in biological productivity has occurred in the Hoover Dam tailwater since the late 1970s. Water nutrient and chlorophyll-*a* concentrations and zooplankton densities have declined since previous tailwater studies (Paulson et al. 1980a, Priscu et al. 1982). However, there is insufficient data before 1976 to determine if productivity decreased in the 1970s relative to prior years.

We conclude that a trophy rainbow trout fishery, equivalent to that of 20-30 years ago, will not return to the Hoover Dam tailwater in the future. Poor survival of stocked fish, due to predation, currently prevents a trophy fishery. Also decreased biological productivity since the mid 1970s may now limit rainbow trout growth and recruitment to trophy sizes.

A popular sport fishery will remain, however, even if current management practices continue. The current trophy striped bass fishery is probably as popular with anglers as the rainbow trout fishery was in the past. In addition, a limited rainbow trout fishery still exists, providing more diverse angling opportunities than many cold tailwaters that support only single species fisheries.

### MANAGEMENT OPTIONS

#### Maintain the status quo.

Since our study was initiated, Lake Mohave and the Willow Beach area have gained a new reputation for providing a quality striped bass fishery. Anglers also continue to use the put-and-take rainbow trout fishery and still catch an occasional trophy rainbow trout. If harvest rates remain low, rainbow trout anglers may lose interest in this fishery, which would lead to stronger criticism of WBNFH stocking "expensive striped bass food." A continuing creel survey measuring angler preferences and harvest rates will help monitor this fishery.

#### Enhance the rainbow trout fishery.

1. Concentrate rainbow trout stocking in Area 7. Returns of fish stocked into the tailwater were low, but higher for fish stocked into Area 7 than for Area 6. It may be more cost effective and more popular with anglers if more fish were stocked in Area 7, especially around Willow Beach where shore angling for

rainbow trout is still popular. However, concentrating the stocked fish in 1 area may also concentrate predators, possibly increasing natural mortality of the stocked fish. Willow Beach National Fish Hatchery should continue to scatter the fish, by boat, within the stocking area. If predation was not a factor, stocking fish near Eldorado may be the best option. Productivity (e.g., zooplankton production) is higher in Eldorado Canyon than in the tailwater. Thus, fish stocked in this area may show better growth.

2. Stock rainbow trout once every 2 weeks as opposed to once every month. More than 60% of tagged fish harvested were caught within the first 2 weeks of stocking. Fishing pressure is also highest immediately after stocking because anglers have learned that catch rates improve during these times. More frequent stocking may provide a steady source of rainbow trout available to anglers, but may also concentrate predators. Also, more frequent stockings may not be logistically or economically feasible for hatchery operations. Scattering fish throughout a stocking area and stocking at night may decrease striped bass predation. Further research is needed to evaluate these options.
3. Stock larger rainbow trout than the current 203-254 mm (stock) size fish. Return rates of stocked rainbow trout averaging 334 and 327 mm were 47% and 22%, respectively, compared to 1 and 2% for stock size fish (Ariz. Game and Fish Dep., unpubl. data). This suggests that larger rainbow trout are more successful at avoiding striped bass predation. However, growing rainbow trout to 330 mm required higher costs for food and raceway maintenance (Ariz. Game and Fish Dep., unpubl. data). Willow Beach National Fish Hatchery would have to assess if this alternative was economically feasible from a hatchery perspective. Stocking a percentage of 330 mm rainbow trout along with regular stock size fish is another option warranting further consideration.
4. Evaluate techniques to reduce the striped bass population in the Hoover Dam tailwater and Lake Mohave. This option would be an attempt to decrease predation on rainbow trout by reducing striped bass numbers. It may be difficult to selectively reduce the striped bass population without detrimental

impacts on nontarget native and sport fish. Opposition would be voiced by striped bass anglers as well.

5. Promote stocking dates to increase angling pressure immediately after rainbow trout are stocked. Increased fishing pressure may increase the harvest before stocked fish succumb to predation.

#### **Manage for trophy striped bass.**

1. Changes in size and bag limits may enhance the trophy striped bass fishery. For example, a slot limit which promotes the harvest of small striped bass, but protects large striped bass, could increase the trophy striped bass population. However, higher numbers of large striped bass in the Hoover Dam tailwater and Lake Mohave would likely increase predation rates on rainbow trout.
2. Investigate ways to enhance threadfin shad recruitment in Lake Mohave. An increased forage base in the reservoir may support the striped bass population and concentrate large striped bass in the reservoir rather than the tailwater. However, the striped bass population may expand in response to increased forage, and continue to prey on stocked rainbow trout.

#### **Cease stocking rainbow trout.**

A creel return of 2.6% may not be economically justifiable. Willow Beach National Fish Hatchery currently spends \$0.59 on each rainbow trout stocked (J. Hanson, Willow Beach Nat. Fish Hatchery, pers. commun.). Therefore, \$22.69 is spent for each fish returned to the creel. However, if rainbow trout stocking is halted, striped bass may switch to preying on razorback suckers or bonytail chubs.

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Appendix A. Rainbow trout food items, Hoover Dam tailwater, July 1993-October, 1995.<sup>a</sup>

Food item	% of stomachs containing food item	% of total no. of food items	% of total volume of food items	Mean of volume % of food items <sup>b</sup>
Algae	23.4	0.1	20.4	8.7
Aquatic macrophytes	44.6	0.2	31.5	11.2
Lumbricidae	1.1	<0.1	2.0	0.3
Cladocera	52.0	40.6	3.9	5.8
Copepoda	9.1	0.3	<0.1	<0.1
Ostracoda	1.1	<0.1	<0.1	<0.1
<i>Hyallela azteca</i>	21.7	6.7	7.7	2.5
Unidentifiable Amphipoda	8.6	0.2	<0.1	<0.1
Hydracarina	24.6	0.8	<0.1	<0.1
Aquatic Hemiptera	20.0	2.7	2.7	3.0
Chironomid larvae	56.6	3.8	0.4	0.4
Chironomid pupae	85.1	43.4	22.3	18.2
Terrestrial Insecta	29.7	0.9	2.7	4.6
<i>Lymnaea</i> spp.	1.1	<0.1	<0.1	<0.1
<i>Physa</i> spp.	8.0	0.3	3.8	2.0
Planorbidae	1.1	<0.1	<0.1	<0.1
Unidentifiable Gastropoda	2.8	<0.1	0.2	0.2
<i>Corbicula fluminea</i>	1.1	<0.1	<0.1	<0.1
Rainbow trout	0.6	<0.1	0.1	<0.1
Striped bass	0.6	<0.1	<0.1	<0.1
Unidentifiable fish remains	7.4	0.1	2.3	5.3

<sup>a</sup> n = 175 stomachs; an additional 9 stomachs were empty and not included in analyses.

<sup>b</sup> The average percentage that each food category contributed to the total volume of food in each stomach (Wallace 1981).

Appendix B. Median nutrient and chlorophyll-*a* concentrations at Eldorado, Monkey Hole, Ringbolt Rapids, and Hoover Dam, Hoover Dam tailwater, August 1993-December 1995.

Site	Total phosphorus <sup>a</sup> (mg/l)	NO <sub>2</sub> + NO <sub>3</sub> (mg/l)	Total Kjeldahl nitrogen (mg/l)	Chlorophyll- <i>a</i> (mg/m <sup>3</sup> )
Hoover Dam				
n	28	28	28	26
Median	--	0.372	0.234	0.20
Range	<0.005 - <0.020	0.340 - 0.450	0.156 - 0.266	0.05 - 0.48
Ringbolt Rapids				
n	22	22	22	23
Median	--	0.376	0.205	0.53
Range	<0.005 - 0.024	0.328 - 0.432	0.182 - 0.276	0.19 - 1.55
Monkey Hole				
n	32	32	32	26
Median	--	0.364	0.220	0.52
Range	<0.005 - <0.020	0.323 - 0.410	0.164 - 0.297	0.08 - 1.01
Eldorado				
n	32	32	32	25
Median	--	0.312	0.240	0.67
Range	<0.005 - 0.023	0.144 - 0.381	0.132 - 0.317	0.24 - 3.34

<sup>a</sup> Phosphorus samples from August 1993-August 1994, October 1995, and December 1995 were analyzed with a minimum detection level of 0.02 mg/l. Samples collected from October 1994-August 1995 were analyzed with a minimum detection level of 0.005 mg/l.

Appendix C. Ranges of physicochemical values measured at Eldorado (EL), Monkey Hole (MH), Ringbolt Rapids (RR), and Hoover Dam (HD), Hoover Dam tailwater, October 1993-December 1995.

Year	Month	Station	pH	Conductivity ( $\mu$ S/cm)	Dissolved Oxygen (mg/l)	Temp. (C)	Salinity (%)
1993	Oct	EL <sup>a</sup>	7.66-8.25	1.15-1.17	-- <sup>b</sup>	13.7-20.8	0.05
		MH	7.60-7.97	1.12-1.15	-- <sup>b</sup>	13.2-13.5	0.05
		RR	7.63-7.92	0.88-1.15	-- <sup>b</sup>	13.1-13.3	0.03-0.05
	Dec	EL	7.74-7.90	1.09-1.11	7.36-7.73	12.9-13.3	0.04
		MH	7.66-7.90	1.09-1.10	6.80-7.04	13.0	0.03-0.04
		HD	7.63-7.78	0.84-1.10	6.70-6.85	13.0-13.1	0.03
1994	Feb	EL	7.65-7.84	0.84	9.33-9.41	11.6-11.7	0.04
		MH	7.70-7.76	1.09-1.10	8.59-8.75	11.9-12.1	0.03
		RR	7.75-7.80	0.83	8.60-8.91	12.2	0.04
		HD	7.68-7.81	1.08-1.09	8.09-8.37	11.9	0.04
	Apr	EL <sup>a</sup>	7.71-7.89	1.10-1.11	8.60-9.84	12.8-14.8	0.04
		MH	7.77-7.89	1.08-1.11	9.02-9.41	12.4-12.7	0.04
		RR	7.76-7.94	1.08-1.11	9.09-9.28	12.3-12.6	0.04
		HD	7.70-7.78	1.09-1.11	8.54-8.83	11.9-12.0	0.04
	Jun	EL <sup>a</sup>	7.88-8.22	1.15-1.16	8.01-8.50	16.2-21.0	0.05
		MH	7.86-8.01	1.12-1.15	7.76-8.53	12.9-13.6	0.05
		RR	7.78-7.95	1.11-1.14	7.21-8.17	12.8-13.1	0.04-0.05
		HD	7.70-7.78	1.11-1.13	6.89-7.18	12.7-13.0	0.04-0.05
	Aug	EL <sup>a</sup>	7.84-8.21	1.16-1.23	7.93-9.00	19.4-28.4	0.05
		MH	7.65-7.76	1.15-1.21	8.02-8.54	14.4-15.2	0.05
		RR	7.68-7.73	1.11-1.19	7.58-7.85	13.8-14.2	0.05
		HD	8.84-9.00	1.17-1.19	6.59-6.94	13.2-13.6	0.05
	Oct	EL <sup>a</sup>	7.40-7.60	1.17-1.18	7.60-9.04	13.9-17.2	0.05
		MH	7.42-7.54	1.17-1.19	6.27-6.70	13.7-13.9	0.05
		RR	7.39-7.46	1.17-1.19	6.68-6.92	13.4-13.5	0.05
		HD	7.39-7.65	1.16-1.19	5.77-5.86	13.2-13.4	0.05



## Appendix C. (continued.)

Year	Month	Station	pH	Conductivity ( $\mu$ S/cm)	Dissolved Oxygen (mg/l)	Temp. (C)	Salinity (%)
1994	Dec	EL	7.45-7.64	1.16-1.18	8.73-8.80	12.0	0.05
		MH	7.55-7.62	1.16-1.17	7.29-7.87	12.5	0.05
		RR	7.05-7.40	1.15-1.16	6.50-6.57	12.2-12.3	0.05
		HD	6.94-7.22	1.14-1.16	6.16-6.28	12.3-12.4	0.05
1995	Feb	EL	7.57-7.66	1.15-1.17	9.19-9.53	12.4	0.05
		MH	7.40-7.54	1.13-1.15	7.25-7.31	11.9-12.0	0.05
		RR	7.50-7.60	1.14-1.16	8.34-8.69	12.5-12.6	0.05
		HD	7.46-7.57	1.14-1.16	8.18-8.36	12.3	0.05
	Apr	EL	7.53-7.55	1.14-1.16	9.24-9.34	13.0-13.1	0.05
		MH	7.14-7.41	1.13-1.15	7.45-7.77	12.4-12.6	0.05
		RR	7.27-7.37	1.13-1.15	7.30-7.50	12.3-12.4	0.05
		HD	7.57-7.59	1.14-1.16	7.59-7.67	12.5	0.05
	Jun	EL <sup>a</sup>	7.88-8.10	1.12-1.15	8.39-9.03	17.0-20.8	0.04-0.05
		MH	7.74-7.80	1.10-1.12	6.94-7.53	13.8-14.3	0.04-0.05
		RR	7.75-7.89	1.11-1.15	7.20-7.83	13.5-14.0	0.04
		HD	7.68-7.72	1.11-1.12	6.56-6.98	13.1-13.3	0.05
	Aug	EL <sup>a</sup>	7.62-8.00	1.15-1.17	8.34-8.97	19.8-26.2	0.05
		MH	7.57-7.60	1.11-1.12	7.49-7.61	15.2-15.5	0.04
		RR	7.53-7.55	1.11-1.14	6.85-7.33	13.9-14.4	0.04
		HD	7.45	1.11	6.46-6.91	13.4-13.5	0.05
	Oct	EL	7.57-7.76	1.12-1.15	8.05-10.0	14.7-17.6	0.05
		MH	7.38-7.40	1.12-1.14	7.31-7.80	14.0-14.6	0.04
		RR	7.39-7.41	1.10-1.11	7.41-8.01	14.4-14.7	0.04
		HD	7.28-7.31	1.11	6.09-6.35	14.0-14.2	0.04
	Dec	EL	7.96-8.01	1.07-1.09	7.26-7.54	13.4	0.04
		MH	7.94-8.09	1.07-1.09	6.05-6.34	13.7	0.04
		RR	7.99-8.05	1.07-1.09	6.66-6.84	14.2-14.3	0.04
		HD	7.98-8.06	1.06-1.08	6.25-6.43	14.0-14.1	0.04

<sup>a</sup> Water was thermally stratified at this station.<sup>b</sup> Not measured due to equipment failure.

## Appendix D. Sources of eyed rainbow trout eggs received by Willow Beach National Fish Hatchery, 1962-1995.

Egg Source	% of eggs received 1962-1975	% of eggs received 1976-1995	% of eggs received 1962-1995
Beity's Resort *	1.13		0.37
Bellvue State Hatchery, Bellvue, Colo.		1.08	0.73
California, State of		1.08	0.73
Caribou Trout Ranch, Id.	27.72	1.08	9.55
Colorado, State of		0.54	0.37
Creston NFH, Kalispell, Mont.		8.15	5.51
Crystal River State Hatchery, Colo.		29.34	19.85
Daniel State Hatchery, Wyo.	2.27		0.74
Ennis NFH, Ennis, Mont.	4.54	32.06	23.16
Erwin NFH, Erwin, Tenn.		7.06	4.77
Fish Lake Hatchery, Fish Lake, Ut.		2.17	1.47
Ford State Hatchery, Ford, Wash.	1.13		0.37
Hartman Private Hatchery, Creede, Colo.	1.13		0.37
Hot Creek Hatchery, Mammoth, Calif.	5.68		1.83
Jocko River Hatchery, Arlee, Mont.		2.71	1.83
McLeary Trout Lodge *	1.13		0.37
Mt. Lassen Trout Ranch, Calif.	7.95	0.54	2.94
Mt. Shasta State Hatchery, Calif.	3.40		1.10
Mt. Whitney State Hatchery, Calif.	1.13		0.37
Nashua NFH, Nashua, N.H.	1.13		0.37
Paradise Brook Trout Co. *	6.81		2.20
Ranch A Hatchery *		0.54	0.37
San Joaquin State Hatchery, Friant, Calif.	3.40		1.10
Saratoga NFH, Wyo.	9.09	3.26	5.14
Soap Lake Trout Lodge, Wash.	6.81	1.08	2.94
Soda Springs Hatchery, Id.	6.81		2.20
State Hatchery, Tensleep, Wyo.		1.08	0.73
Story State Hatchery, Wyo.	2.27	0.54	1.10
Valley, Wash.	3.40		1.10
White Sulphur Springs NFH, W.Va.	1.13	7.60	5.51
Williams Creek NFH, Whiteriver, Ariz.	1.13		0.37
Winthrop NFH, Winthrop, Wash.	1.13		0.37

\* State unknown.



— NOTES —

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**Abstract:** We conducted this study from 1993-1995 to determine what caused a decline in numbers of trophy ( $\geq 508$  mm total length) rainbow trout (*Oncorhynchus mykiss*) harvested from the Hoover Dam tailwater, and to learn what factors currently limit the fishery. The Hoover Dam tailwater supported a trophy rainbow trout fishery in the 1960s and early 1970s. By the late 1970s, the percentage of trophy fish harvested decreased, as did angling effort. Currently, a put-and-take rainbow trout fishery exists, along with a striped bass (*Morone saxatilis*) fishery. We investigated stocking practices, and determined diet and sources of mortality of stocked rainbow trout. We also surveyed indicators of biological production in the tailwater. Angling exploitation of stocked fish was 2.6%, but annual survival was near 0. Rainbow trout comprised 98% of food item volume in large ( $\geq 400$  mm) striped bass stomachs. Occurrence of rainbow trout in large striped bass stomachs decreased, while occurrence of cladocerans and chironomid pupae increased,  $> 2$  weeks after rainbow trout were stocked. This change in diet suggests that stocked fish were quickly depleted by predation, forcing large striped bass to switch to other food items. Chironomid pupae, aquatic macrophytes, and algae made up 18.8, 11.6, and 10.0% of the rainbow trout diet, respectively. Chlorophyll-*a* and nutrient concentrations were lower than those measured in the Hoover Dam tailwater in the mid 1970s. Willow Beach National Fish Hatchery typically stocked catchable ( $\bar{x} = 203$  mm) fish from 1963-1973. However, mainly subcatchable fish were stocked from 1974-1978, which may have led to decreased survival and growth of these fish. In addition, rainbow trout growth may have decreased due to a declining threadfin shad (*Dorosoma petenense*) forage base. Striped bass predation currently limits the rainbow trout fishery. Rainbow trout returns may be improved by stocking fish every 2 weeks, stocking larger fish, and concentrating stocking near Willow Beach Marina.

**Key words:** angling exploitation, Colorado River, *Morone saxatilis*, nutrients, *Oncorhynchus mykiss*, rainbow trout, striped bass, tailwater.

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*Arizona Game and Fish Department file photo (Page 26)*

*George Andrejko (Pages iv, vi, 8, and 14)*

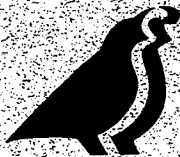
*Scott Bryan (Page 7)*

*Jody Walters (Cover, page 13)*

*"For Angling may be said to be so like the Mathematicks, that it can never be fully learnt; at least not so fully, but that there will still be more new experiments left for the trial of other men that succeed us."*

*Izaak Walton*

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